TRANSMISSION3D

User's Manual

Advanced Numerical Solutions

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PREFACE

The Transmission3D computer program is the culmination of many years of work, During this time, we have received active support and encouragement from many people. We would especially like to thank Timothy Krantz of the Army Research Laboratory at the NASA Glenn Research Center for his support and encouragement. We are grateful for the support of the U.S. Army's SBIR program, without which the development of this program would not have been possible.

CHAPTER 1

INTRODUCTION

The capabilities of the *Transmission3D* software package form a superset of those of the *Planetary3D* package. While *Planetary3D* is capable of analyzing planetary systems of arbitrary complexity, it is limited to those comprised of spur and helical gears with parallel axes. *Transmission3D* removes these restrictions, and can analyze systems with non-parallel axes. These systems may have arbitrary three-dimensional gearing, including hypoid, spiral bevel, crossed helicals, or even straight bevel gears. *Transmission3D* can analyze all the variations of three-dimensional planetary systems (Table 1.1) that the *Planetary3D* package is capable of analyzing, but can also handle system such as vehicle automotive rear axles which may contain hypoids and straight bevel differentials (Figure 1.1), and a helicopter gearbox which contains a planetary reduction stage coupled with a spiral bevel set.

The analytical technique used in the software package combines a unique, semi-analytical finite element approach with detailed contact modeling at the tooth mesh. This approach was specifically developed to examine the mechanics of precisely machined, contacting elastic bodies such as gears. The semi-analytical finite element approach does not require a highly refined mesh at the contacting tooth surfaces which substantially reduces the computational time. The *Transmission3D* analysis package provides a more accurate and comprehensive study of planetary gear static analysis than is reasonably possible, or has been conducted, with conventional finite element analysis.

Contact pair analysis geared systems poses many technical difficulties for general purpose finite element software:

- *Size of the contact zone:* The width of the contact zone in typical gearing applications is two orders of magnitude smaller than the dimensions of the gear teeth themselves. In order to model the contact conditions with sufficient accuracy, a general purpose non-linear finite element program needs to have a large number of nodes (a very fine mesh) inside the contact zone. To run such a contact model, the fine mesh in the contact zone has to transition into a much coarser mesh over the rest of the gear. The location of the contact zone, however, changes as the gears move. This means that either the gear finite element model should be re-meshed for each time instant, or that the finite element mesh be highly refined over its entire surface area. Both these alternatives lead to unacceptably high computational costs. Our approach has been to use the finite element models only to compute relative deformation

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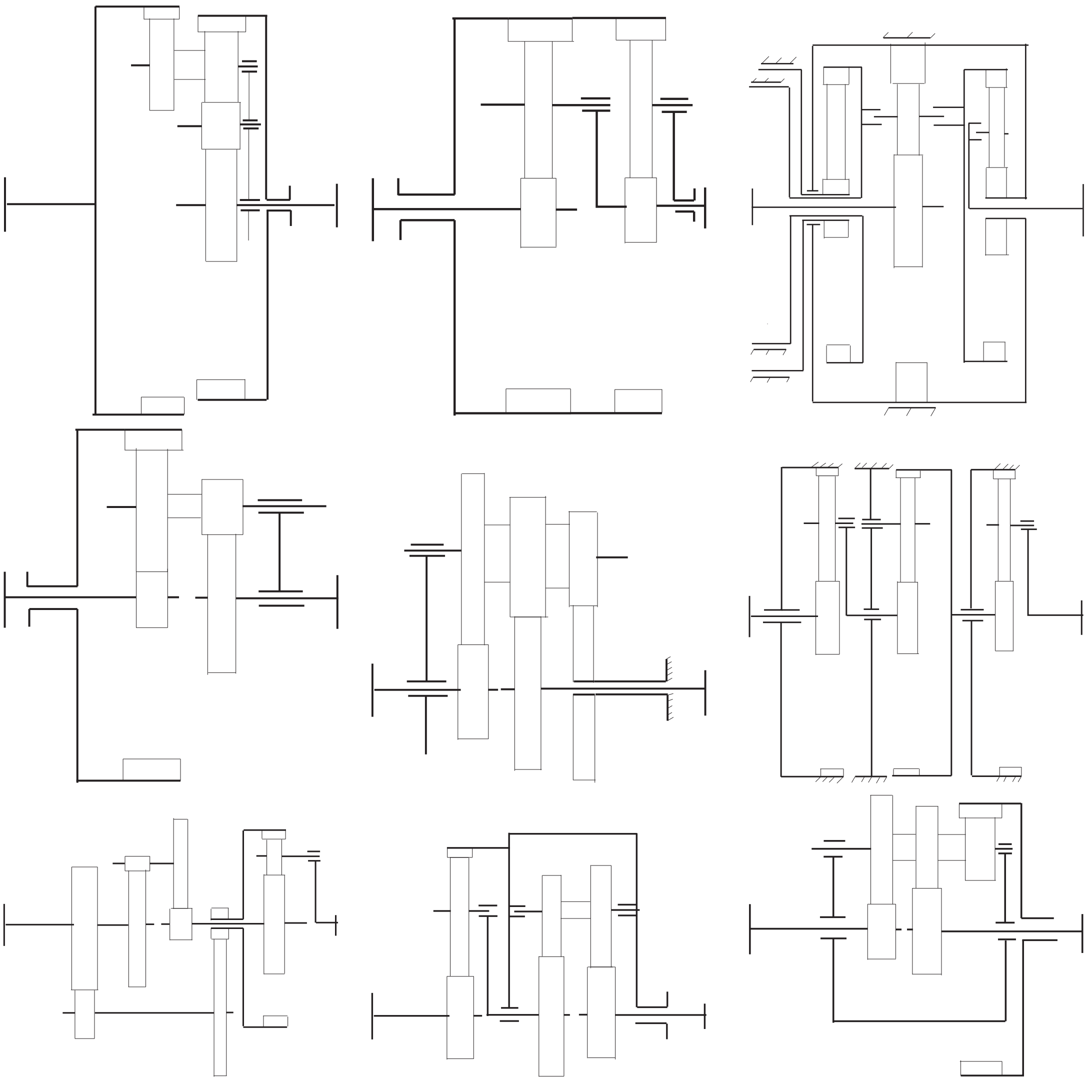
Table 1.1 Examples of planetary systems that can be modeled using the *Transmission3D package*



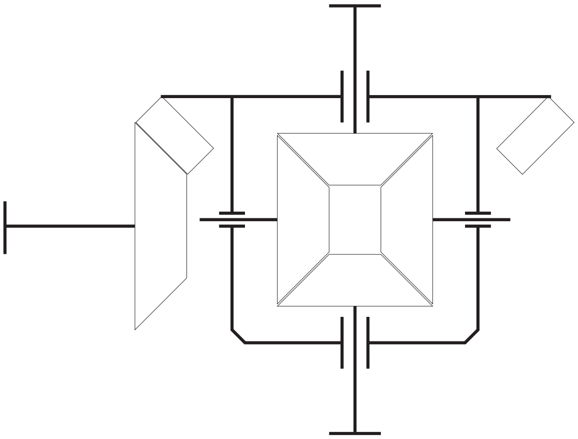


Figure 1.1 Schematic of an automotive rear axle differental.

and stresses for points that are away from the contact zones. For points within the contact zone, we use semi-analytical techniques to compute the relative deformations and stresses. The ‘near field semi-analytical solution and the ‘far field finite element solutions are matched at a ‘matching surface. Such a model is significantly difficult to program on a computer, but once implemented, can provide much better resolution without using a highly refined finite element mesh.

- *Rigid body degrees of freedom in the system:* In multi-mesh gear systems like planetary transmissions, there are many rigid body degrees of freedom or mechanisms that are constrained only by the contact conditions. This means that if a non-linear finite element code with gap elements is used, then the incremental stiffness matrices become singular. Most commercial codes don’t work when this happens. Some manupalations are commonly used, such as adding imaginary linear and torsional springs to make the system stiffness matrices non-singular. The spring stiffness can be made small, but the accuracy of results computed by such almost singular stiffness matrices is questionable. Our approach has been to attach a reference frame to each individual component, and to carry out the finite element computations for each individual component separately in its own reference frame. As long as each finite element mesh is sufficiently well constrained to its reference frame, the stiffness matrices are well behaved. The free mechanisms in the system can be modeled by allowing the reference frames to move freely. The contact solver used is based on the *Revised Simplex Solver*. This Solver is commonly used to solve quadratic programming problems. It can take into account any free mechanisms in the system while computing the contact loads.

- *Large number of degrees of freedom:* For a typical transmission system models, the total number of finite element degrees of freedom can be extremely large. This is so even with the finite element model refined only as much as is necessary for the far field solution. The total number of finite element degrees of freedom is approximately proportional to the total number of teeth. The amount of CPU time and memory needed to run a finite element analysis with such a large degree of freedom would make it impractical. We have resorted to using a hierarchical representation of the system, in which the system is built from many substructures, with each substructure in turn being composed of many substructures. The processes of stiffness decomposition and load vector back-substitution now become very complex, and involve multiple recursive traversals of the substructure hierarchy. However, it is now possible to keep CPU requirements within practical limits.

- *Convergence of conditions at contact interfaces:* Poor convergence of contact conditions at interfaces is one of the biggest problems caused by using a general non-linear solver to solve a problem with contact constraints. The constraints imposed by the contact between mating surfaces are essentially linear inequality constraints. When a general-purpose non-linear solver is used to solve this problem, convergence is not guaranteed, and if it does occur, it is usually very slow. The *Revised Simplex solver* that we use provides a guarantee of convergence within a predetermined number of iterations. Furthermore, ill-posed contact problems can be detected even before the solution process is started. The solver is specifically designed for the linear inequality type constraints found in contact problems.

- *System Kinematics:* The nominal position of each individual gear in the system changes with time. The nominal positions of the components are determined by the kinematics of the system. The kinematics of the system affects the nominal sliding velocities and inertial loads. It is very difficult to include this kinematic information into the finite element programs currently available. We have built a special purpose programming language into the software in order to specify the details of the kinematics of each component in the system. Important details such as the kinematic effect of assembly errors, runout and misalignments are easy to apply using this approach.

CHAPTER 2

TRANSMISSION3D SOFTWARE PACKAGE

This chapter explains the various features of the *Transmission3D* software package.

2.1 Transmission3D analysis package

The *Transmission3D* package is based upon the *Calyx*, *Multyx* and *Guide* computer programs.

Calyx is a powerful contact analysis code capable of analyzing a variety of contact problems, including 2D and 3D dynamic and static analysis of systems such as gears, compressors, and brakes. Because *Calyx* has to be capable of handling a variety of problems, it communicates with the outside world through a programming language. The programming language interface of *Calyx* brings flexibility at the expense of ease of use. Such an interaction is appropriate for an advanced *Calyx* user, but not for a gear design engineer.

In order to address this issue, the program *Multyx* is used. *Multyx* is capable of communicating through an easy to use menu-based interface. It translates user commands into the appropriate programming language statements and sends them on to *Calyx*. A typical user does not even need to know that *Calyx* is running in the background.

In addition to the user interface, *Multyx* also has built-in model generators. The Planetary models described in this manual are all generated by *Multyx*. It also has post-processing software called *Iglass* and data extraction code, to help you extract the results of analysis from *Calyx*.

Multyx and *Calyx* are designed as portable code, and can run on any system that supports standard C++. In order to keep it portable, *Multyx*'s menu system is command line based, and does not use any of the GUI features such as buttons, windows or mouse interaction. The following dialog shows some of the command line interface of *Multyx*.

```
E:>multyx
MultyX v.1.06, Copyright Advanced Numerical Solutions Dec 21 2000
MultyX>pre view
MultyX.PreProc.View>?
MENU            Show menu
```

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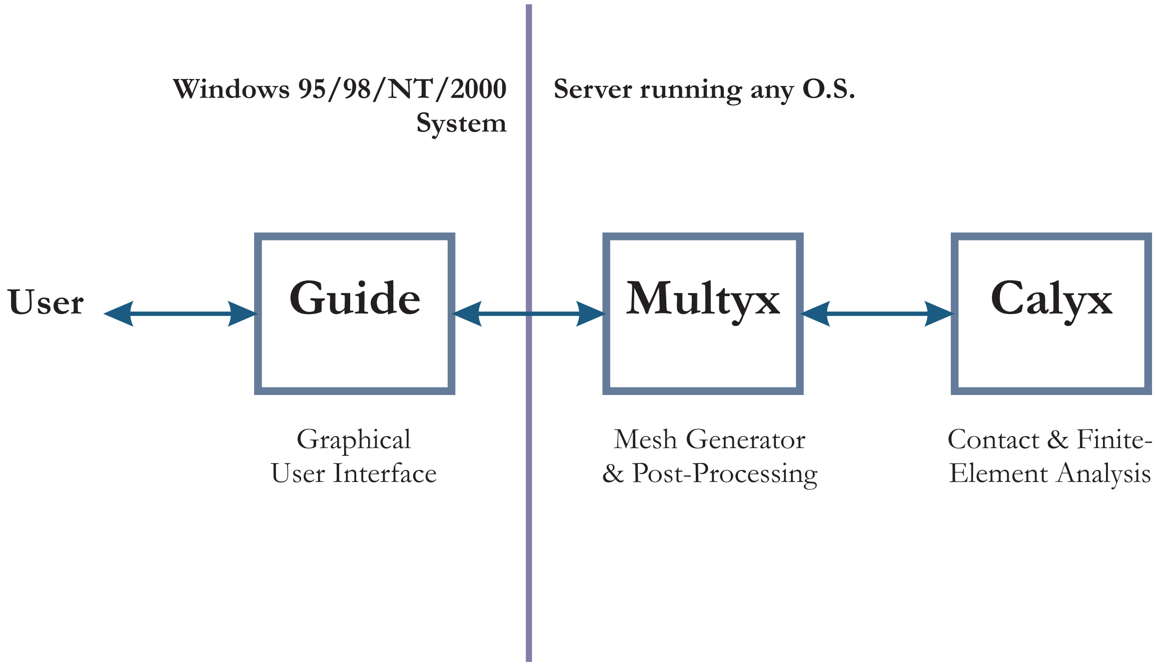
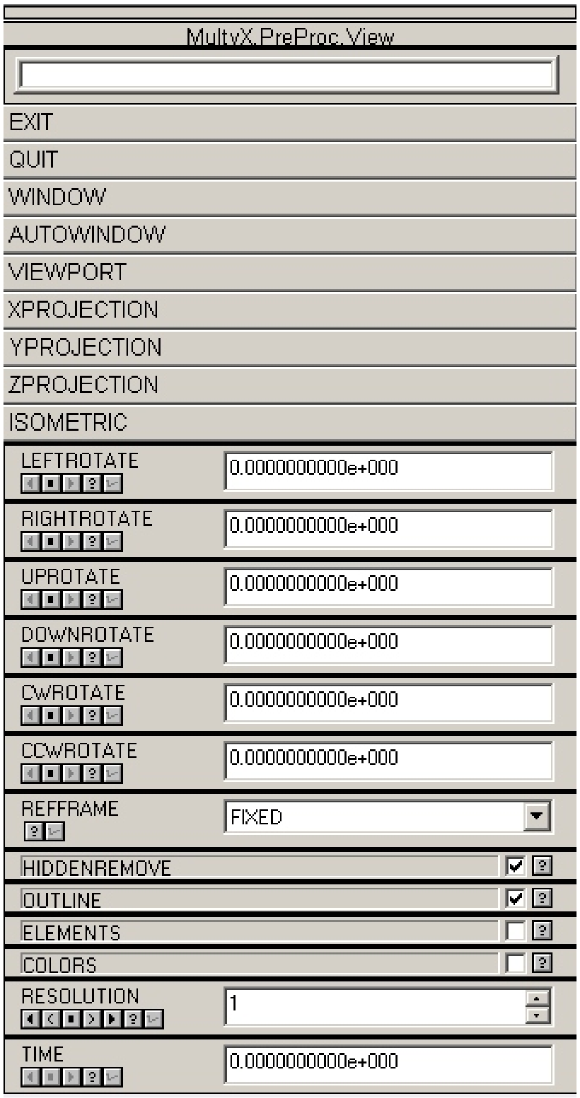

Windows 95/98/NT/2000
System
Server running any O.S.
User
Guide
Multyx
Calyx
Graphical
User Interface
Mesh Generator
& Post-Processing
Contact & Finite-
Element Analysis

Figure 2.1 The computer programs in the *Transmission3D* analysis package

```
?                Show menu
HELP             Show menu
EXIT             Accept changes and return.
QUIT             Discard changes and return.
WINDOW           Adjust Window.
AUTOWINDOW       Size window automatically.
VIEWPORT         Adjust Viewport.
XPROJECTION      Project on Y-Z plane along X axis.
YPROJECTION      Project on X-Z plane along Y axis.
ZPROJECTION      Project on X-Y plane along Z axis.
ISOMETRIC        Use an Isometric-Projection.
LEFTROTATE       Rotate to left as seen in window.
RIGHTROTATE      Rotate to right as seen in window.
UPROTATE         Rotate upward as seen in window.
DOWNROTATE       Rotate downward as seen in window.
CWROTATE         Rotate clockwise as seen in window.
CCWROTATE        Rotate counter-clockwise.
REFFRAME         (FIXED)         Reference frame to be used for drawing
HIDDENREMOVE     (TRUE )         Whether to enable hidden line removal.
OUTLINE          (TRUE )         Whether to draw the model outline.
ELEMENTS         (FALSE)         Whether to draw individual finite elem
COLORS           (FALSE)         Whether to render the model in color
RESOLUTION       2               Graphics resolution level.
TIME             0.000000E+000   Time at which to draw system.
MultyX.PreProc.View>
```

Guide is a program that provides a Graphical User Interface (GUI) to *Multyx*. *Guide* translates each of *Multyx*’s dialogs and presents them to you in a graphical form. The command line menu described above is presented as shown in Figure 2.2.


MultyX.PreProc.View
EXIT
QUIT
WINDOW
AUTOWINDOW
VIEWPORT
XPROJECTION
YPROJECTION
ZPROJECTION
ISOMETRIC

LEFTROTATE 0.0000000000e+000

RIGHTROTATE 0.0000000000e+000

UPROTATE 0.0000000000e+000

DOWNROTATE 0.0000000000e+000

CWROTATE 0.0000000000e+000

CCWROTATE 0.0000000000e+000

REFFRAME FIXED

HIDDENREMOVE ☑

OUTLINE ☑

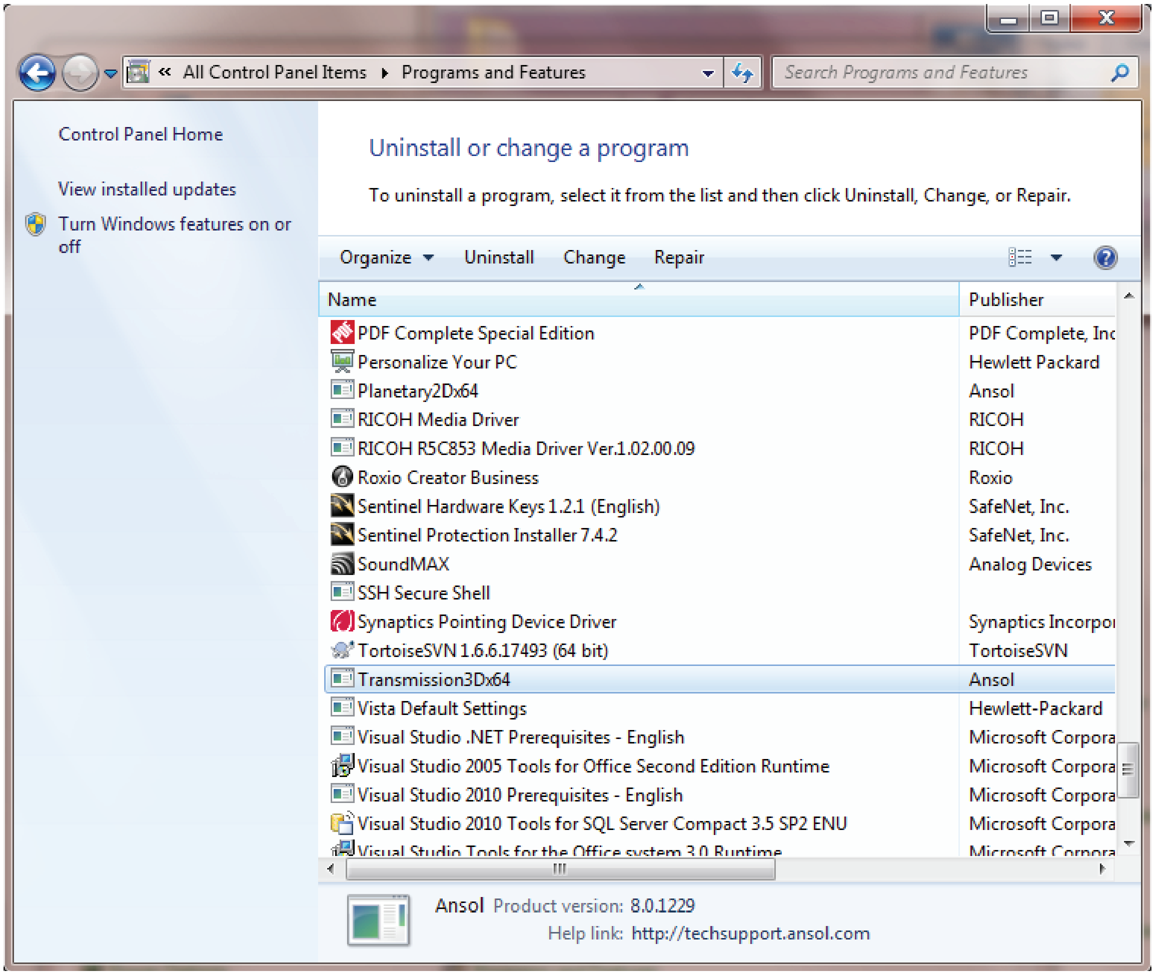
ELEMENTS ☐

COLORS ☐

RESOLUTION 1

TIME 0.0000000000e+000

Figure 2.2 The menu presented to the user by Guide


« All Control Panel Items ▸ Programs and Features
Search Programs and Features
Control Panel Home
View installed updates
Turn Windows features on or off
Uninstall or change a program
Organize ▾
Uninstall
Change
Repair

To uninstall a program, select it from the list and then click Uninstall, Change, or Repair.

Name	Publisher
PDF Complete Special Edition	PDF Complete, Inc
Personalize Your PC	Hewlett Packard
Planetary2Dx64	Ansol
RICOH Media Driver	RICOH
RICOH R5C853 Media Driver Ver.1.02.00.09	RICOH
Roxio Creator Business	Roxio
Sentinel Hardware Keys 1.2.1 (English)	SafeNet, Inc.
Sentinel Protection Installer 7.4.2	SafeNet, Inc.
SoundMAX	Analog Devices
SSH Secure Shell	
Synaptics Pointing Device Driver	Synaptics Incorpo
TortoiseSVN 1.6.6.17493 (64 bit)	TortoiseSVN
Transmission3Dx64	Ansol
Vista Default Settings	Hewlett-Packard
Visual Studio .NET Prerequisites - English	Microsoft Corpora
Visual Studio 2005 Tools for Office Second Edition Runtime	Microsoft Corpora
Visual Studio 2010 Prerequisites - English	Microsoft Corpora
Visual Studio 2010 Tools for SQL Server Compact 3.5 SP2 ENU	Microsoft Corpora
Visual Studio Tools for the Office system 3.0 Runtime	Microsoft Corpora

Ansol Product version: 8.0.1229
Help link: http://techsupport.ansol.com

Figure 2.3 Uninstalling an Old Version of Transmission3D on Windows 7.

Although *Guide* enhances the friendliness of *Multyx*, it is not required. All the features of *Multyx* can be accessed without *Guide*. The connection between *Guide* and Multyx is based on the TCP/IP telnet protocol when they are running on different computers. When running on the same computer, they communicate through named pipes. *Guide* is a heavy user of advanced operating system features including GUI support, multi-threading support, and inter-process communication support. *Guide* now runs on 32 and 64 bit versions of Windows XP, Windows Vista and Windows 7.

2.2 Installation of the software package on Windows

The procedure for installing the *software analysis package* on windows 95/98/NT platforms is as follows:

- If you have an older version installed, first uninstall it using *ControlPanel/Add Or Remove Programs/Transmission3D* on Vista or *ControlPanel/Programs and Features/Transmission3D* on Windows 7 (Figure 2.3).
- Get the installer file (`Transmission3DWin32.msi` for 32 bit Windows or `Transmission3Dx64.msi` for 64 bit Windows) from Ansol(Advanced numerical solutions) either by email, ftp or on a CD. If you are using an ftp client, make sure that the file is downloaded with ftp in binary mode. Double-click on the `.msi` file to start the installation process. It will ask you questions about where to install the program and where to keep the working directory.

Figure 2.4 Sentinel USB Hardlock/Dongle.

- If you have been provided with a Sentinel Hardlock (Figure 2.4), then double-click and install the Sentinel device driver installer `Sentinel Protection Installer.msi`. Now insert the hardlock. The LED on the hardlock will light up.
- Use the shortcut *Start/Programs/Transmission3D/Install License Key/For All Users* to go to the license key dialog box (Figure 2.5). Paste the license key that has been provided to you into this Dialog box, and press the *Update* button. If the license key is valid, the correct license expiry date will be shown in this dialog box. Hit *Exit*.
- Now you are all set to run the analysis. Start the program by using the icon *Start/ Programs/ Transmission3D/ Guide*.

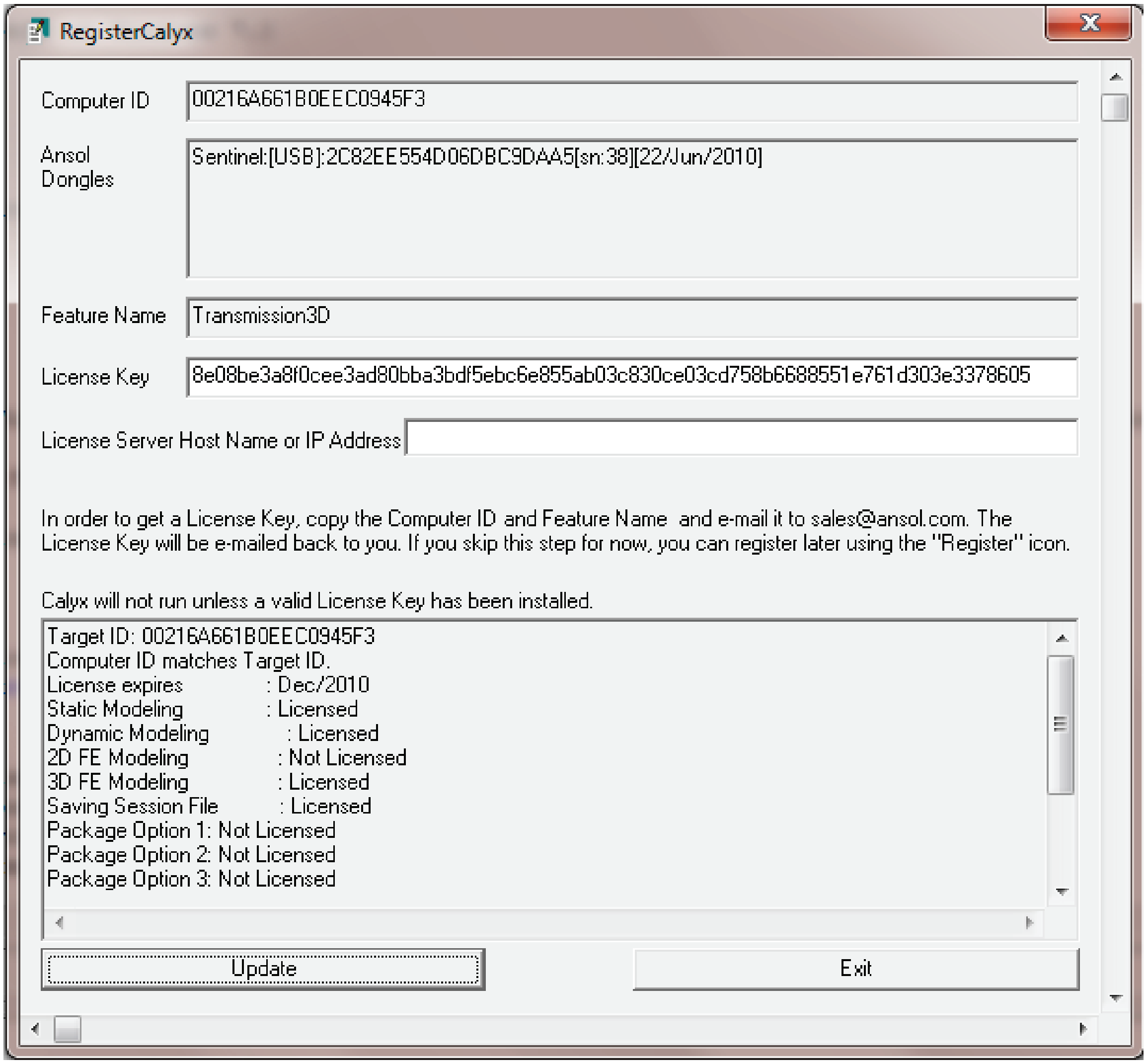
2.3 Installation of the software package on Linux

- The installation will be provided to you as a tarball `T3DDistrib.tar.gz`. Extract all files from this tarball and copy the files to a convenient installation directory (e.g. `/opt/ansol/T3D`).

```
gunzip T3DDistrib.tar.gz
tar -xvf T3DDistrib.tar
mkdir /opt/ansol
mkdir /opt/ansol/T3D
cp -R T3DDistrib/* /opt/ansol/T3D/
```

- Allow read privilege to all files for all users. Allow execute privilege to the files `calyx`, `multyx`, `cvtbdf`,

```
chmod -R o+r /opt/ansol/T3D
chmod o+x /opt/ansol/T3D/calyx
chmod o+x /opt/ansol/T3D/multyx
```



Computer ID: 00216A661B0EEC0945F3

Ansol Dongles: Sentinel:[USB]:2C82EE554D06DBC9DAA5[sn:38][22/Jun/2010]

Feature Name: Transmission3D

License Key: 8e08be3a8f0cee3ad80bba3bdf5ebc6e855ab03c830ce03cd758b6688551e761d303e3378605

License Server Host Name or IP Address:

In order to get a License Key, copy the Computer ID and Feature Name and e-mail it to sales@ansol.com. The License Key will be e-mailed back to you. If you skip this step for now, you can register later using the "Register" icon.

Calyx will not run unless a valid License Key has been installed.

```
Target ID: 00216A661B0EEC0945F3
Computer ID matches Target ID.
License expires            : Dec/2010
Static Modeling            : Licensed
Dynamic Modeling             : Licensed
2D FE Modeling             : Not Licensed
3D FE Modeling             : Licensed
Saving Session File        : Licensed
Package Option 1: Not Licensed
Package Option 2: Not Licensed
Package Option 3: Not Licensed
```

Figure 2.5 The License Key Dialog Box.

```
chmod o+x /opt/ansol/T3D/cvtbdf
```

- If you run the program `calyx`, it will display a computer ID which you can send to us by e-mail. We will generate a license key based on the computer ID and send it back to you:

```
calyx
Environment variable "AnsolCalyx_1_0_LicenseKey" is undefined.
Computer ID=000E0C37CD14A8C00701
Get a valid license key and set the value of the
environment variable "AnsolCalyx_1_0_LicenseKey".
Cmd>End;
```

- Add following environment variable definitions and aliases for all users. For bash:

```
export PATH=$PATH:/opt/ansol/T3D
export CalyxInstallDir=/opt/ansol/T3D
alias Transmission3D='multyx Transmission3Dcr.sdf'
export Transmission3D=<LicenseKey>
```

For c shell:

```
setenv PATH $PATH:/opt/ansol/T3D
setenv CalyxInstallDir /opt/ansol/T3D
alias Transmission3D 'multyx Transmission3Dcr.sdf'
setenv Transmission3D <LicenseKey>
```

Here `<LicenseKey>` should be replaced by the license key that we send you.

- Use the alias `Transmission3D` to start up *Transmission3D*:

```
Transmission3D
`04
MultyX Rev 8.2.17.1276 Copyright ANSol 2010/06/18 14:20:54
License Target ID             : 00219B8DC0F3007F0100
Feature                       : 3D Transmission System Model
Current SDF Version           : 0.1128
License                       : Perpetual
Saving Session File           : Licensed
Static Modeling               : Licensed
Dynamic Modeling              : Licensed
2D FE Modeling                : Licensed
3D FE Modeling                : Licensed
Package Option 1              : Licensed
Package Option 2              : Licensed
Maximum number of Bodies      : 2000
Maximum Contact Constraints   : 20000
Maximum no. of CPUs Licensed  : 16
Did not find session file:
multyx.ses
`
MultyX>
```

CHAPTER 3

PRELIMINARIES

The previous chapter gave an overview of the software architecture. This chapter provides some information to help you get up and running with the program.

3.1 System of units

Any system of units can be used provided that all the inputs provided by you are consistent with this system of units. You are free to choose any units for force, time and length. All the inputs should then be in units that are consistent with this choice. For example, if you choose Kgf as the unit for force, seconds as the unit for time, and cm as the unit for length, then the input torque should be in $Kgf.cm$, the Youngs modulus in Kgf/cm^2, the Diametral pitch in $1/cm$ and the mass density in $Kgf.s^2/cm^4$. Outputs will also appear in consistent units.

3.2 Bodies

In multi-body contact analysis, the term ‘body’ is used to refer to an object that is capable of rigid body motion, and interacts with other bodies through surface contact and bearing connections.

There is a special body called the ‘fixed body’ which refers to ground. Figure 3.1 shows a typical multi body system.

For example, in a *Transmission3D* model of a planetary gear set, the sun, pinions, carrier, shafts and the ring gear are all treated as separate bodies. The sun-pinion, sun-sun and the pinion-ring interaction is through contact. The spider or the carrier supports the planet shafts. The pinions revolve around the central axis while rotating along their own axes at the same time, much like planets revolve around the sun. The interaction between the carrier and the pinion shafts is also through contact.

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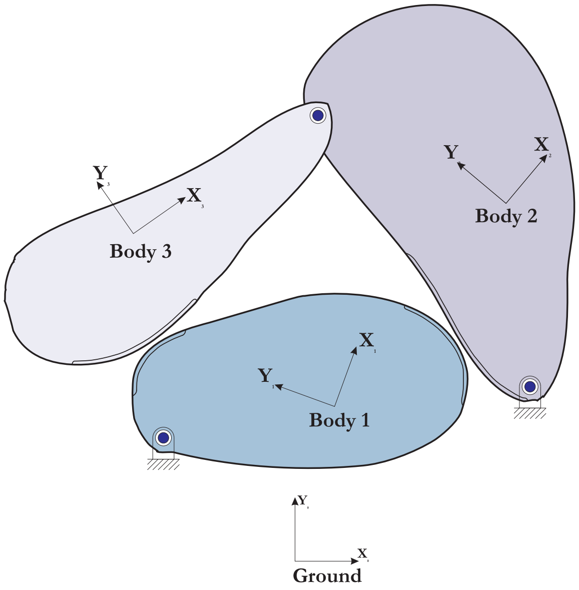
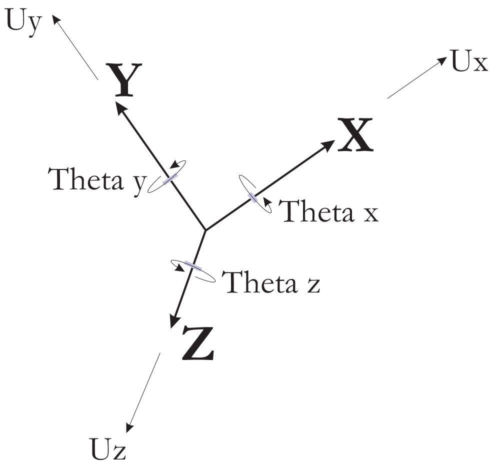


Y3
X3
Body 3
Y
X2
Body 2
Y1
X1
Body 1
Y0
X0
Ground

Figure 3.1 A multi-body system



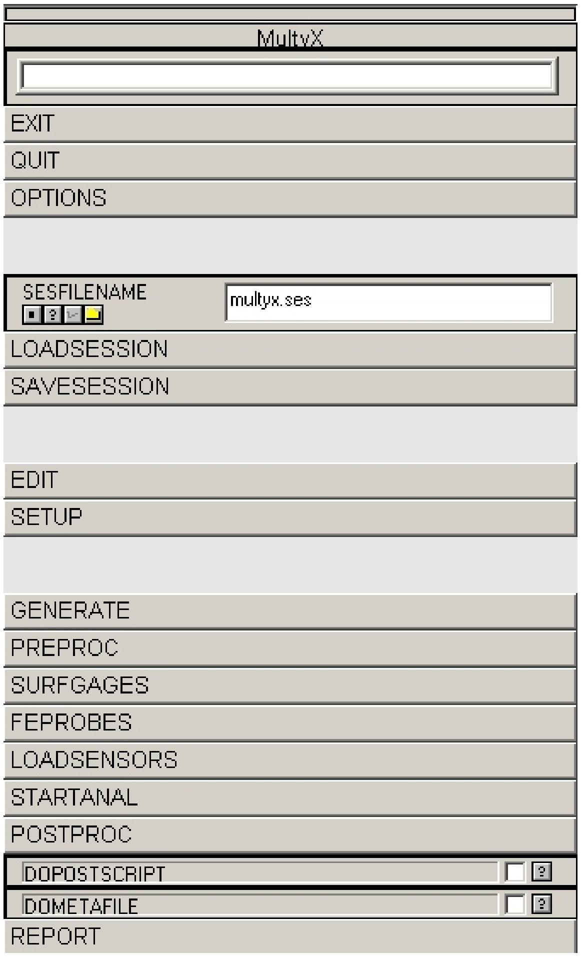
Uy
Y
Ux
X
Theta y
Theta x
Theta z
Z
Uz

Figure 3.2 Reference frame degrees of freedom

3.3 Reference frames

Each of the bodies in the system has a reference frame to which it is rigidly attached. The reference frame has 6 rigid body type degrees of freedom, three translation components U_x, U_y and U_z, and three rotation components θ_x, $\theta_y$and and θ_z (Figure 3.2).

In addition to the body reference frames, there is a special reference frame called the fixed reference frame that is considered as 'ground', and does not move. It is used as the reference for defining the locations of all other reference frames.



SESFILENAME multyx.ses

DOPOSTSCRIPT ☐

DOMETAFILE ☐

Figure 3.3 The main menu.

3.4 The main menu

The *Transmission3D* package is started by clicking on an icon created during the installation process. After the *Transmission3D* package is started, the main menu shown in Figure 3.3 comes up.

All user provided data is saved in a file called the session file. The name of this session files can be changed by typing the name in the SESFILENAME box. Changing the files name does not actually write the data to the new file, nor does it read data from the new file. Data is written to the session file through the SAVESESSION command. Data can be loaded from an existing session file using the LOADSESSION command.

The QUIT command terminates the program without saving any data in the session file. The EXIT command first writes data to the session file, and then terminates the program.

All data entry occurs in a hierarchy of submenus accessed through the EDIT command on this main menu.

After data entry is completed, the GENERATE command may be used to generate the model. At this point, a consistency check is carried out. If any errors or inconsistencies are detected in inputs, then error messages are displayed, and the model is not generated. If the program detects something that it thinks is questionable, but is still able to proceed, then it displays warning messages, but proceeds with generating the model.

The REPORT command is used to generate an ASCII file called `report.txt`, describing all the inputs supplied to the program.

The PREPROC command allows you to graphically inspect the latest model. If you have changed some parameters after the last GENERATE action, then the PREPROC command detects this and calls the GENERATE command itself.You can select the bodies for which you want to check for results in the SELECT menu in the PREPROC panel. The selected bodies can be visualized in the graphics region by clicking on the DRAWBODIES button.

The SETUP command is used to set up an analysis. The SEPTOL, DSPROF and NPROFDIVS menu can be accessed through the SETUP panel. The FEPROBES, SURFGAGES, and LOADSENSORS commands are used to control the data created by the analysis.

STARTANAL command is used to start the analysis and the IGLASS.dat command is used to create a postprocessing file after the analysis is done. IGLASS command is used to graphically inspect the results of the analysis.

CHAPTER 4

THE GRAPHICAL USER INTERFACE

Transmission3D's user interface is presented by *Guide* in graphical form, as shown in Figure 4.1. *Transmission3D* sends out a stream of informational, error and warning messages. These messages are separated by *Guide*, and presented in separate windows as shown. You can activate these message windows by hitting the appropriate “Error”, “Information” or “Warning” tab. Graphical information sent by *Transmission3D* is directed to a graphics window.

4.1 Menu command items

In the example shown in Figure 4.1, the large buttons such as those labeled EXIT ,QUIT, OPTIONS, LOADSESSION, EDIT send commands to *Transmission3D* when hit. In response to the command, *Transmission3D* might carry out an action, as in the case of the LOADSESSION command, or lead you to a different menu, as in the case of the EDIT command. Moving the mouse over a button without depressing it will cause *Guide* to momentarily pop up a balloon (a tool tip) containing a short description of the use of that button. The tool tips can be disabled by the View|DisableToolTips item in the *Guide* main menu.

4.2 Integer menu items

Integer data items are entered through a dialog box of the kind shown in Figure 4.2. The current value appears in a box in the dialog box. If the value of the data item is undefined, then the box appears blank.

4.3 Floating point menu items

Floating point data is entered through the dialog box shown in Figure 4.3.

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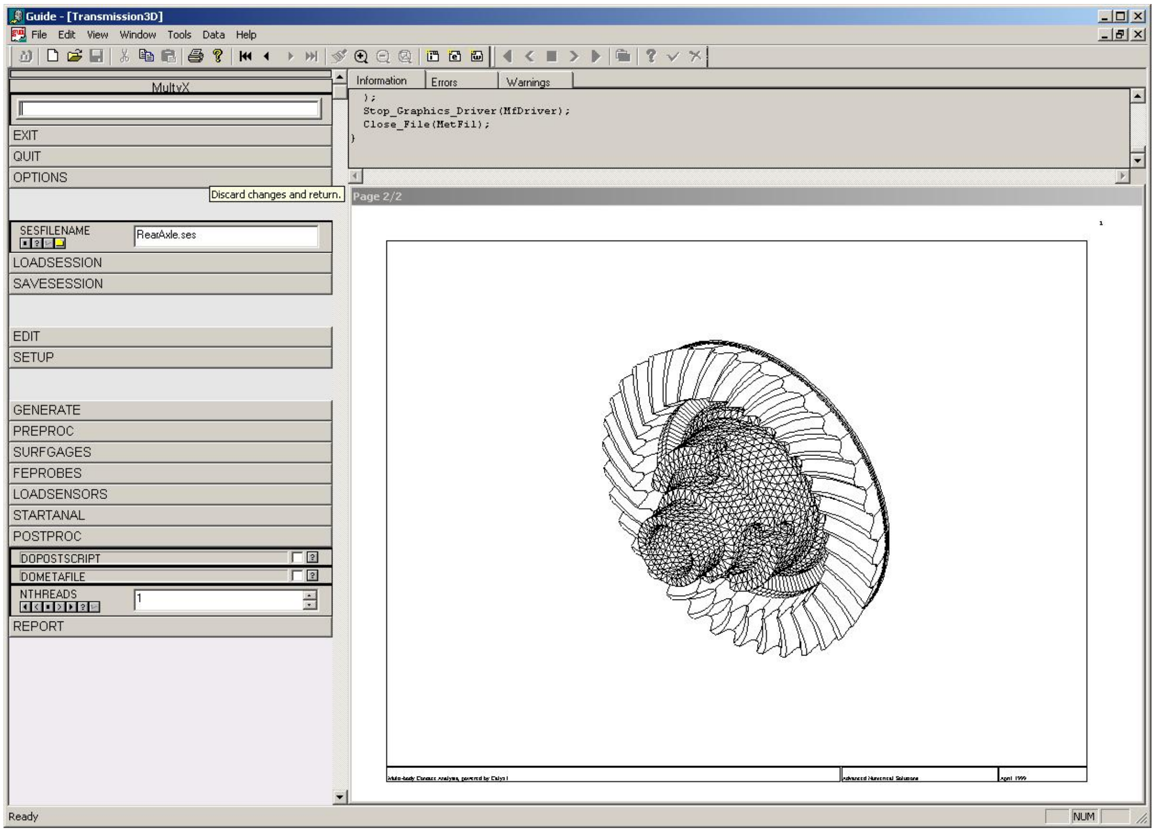


```
  );
  Stop_Graphics_Driver(MfDriver);
  Close_File(MetFil);
}
```

SESFILENAME RearAxle.ses

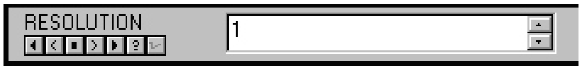
NTHREADS 1

Discard changes and return.

Ready

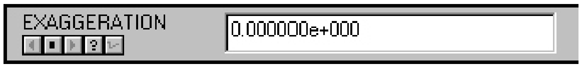
Guide - [Transmission3D]
File
Edit
View
Window
Tools
Data
Help
MultyX
EXIT
QUIT
OPTIONS
LOADSESSION
SAVESESSION
EDIT
SETUP
GENERATE
PREPROC
SURFGAGES
FEPROBES
LOADSENSORS
STARTANAL
POSTPROC
DOPOSTSCRIPT ☐
DOMETAFILE ☐
REPORT
Information
Errors
Warnings
Page 2/2
NUM

Figure 4.1 Transmission3D user interface



RESOLUTION 1

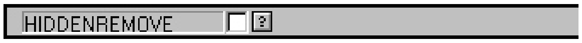
Figure 4.2 An integer data entry box



EXAGGERATION 0.000000e+000

Figure 4.3 An floating point data entry box

4.4 Boolean menu items

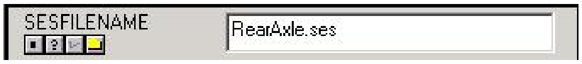


HIDDENREMOVE ☐

Figure 4.4 An boolean data entry box

Boolean data items are those that can only take a YES/NO or TRUE/FALSE type of value. Their value is set by checking or clearing the box as shown in Figure 4.4.

4.5 String menu items

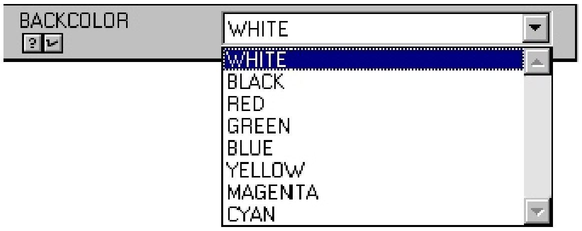


SESFILENAME RearAxle.ses

Figure 4.5 An string data entry box

String data items contain ASCII strings. The dialog box shown in Figure 4.5 allows you to enter string type data.

4.6 Switch type menu items



BACKCOLOR WHITE

Figure 4.6 An switch type data entry box

The last kind of data item is of the ‘switch’ type. This item can be switched between a fixed set of valid choices. The choice is made through a drop down list as shown in Figure 4.6.

4.7 Commonly occurring buttons

The data entry dialog boxes use a few small buttons as short cuts for common tasks as shown in the Table 4.1. Some of these buttons may be disabled depending upon the particular item and its value.

Table 4.1 Common buttons

Button	Purpose
◀	Select the minimum allowable value
<	Decrement the value by 1
■	Select the default value
>	Increment the value by 1
▶	Select the maximum allowable value
📁	Browse for file name
✓	Accept the value just typed in
✕	Discard the value just typed in
?	Get additional information
⏮ ◀ ▶ ⏭	Change the current graphics page
🔍 🔍 🔍	Change the zoom level
🖌	Refresh the graphics page

4.8 Graphics

Guide directs the graphical output from *Transmission3D* to a graphics window. The graphics are stored as separate pages. A new page is started when *Transmission3D* clears the graphics screen. You can move between screens using the ⏮ ◀ ▶ ⏭ buttons on the toolbar.

Double clicking anywhere in the graphics window with the left mouse button or dragging the mouse in the graphics window with the left button depressed lets you zoom in. To zoom out, double-click with the right mouse button. The 🔍 🔍 🔍 buttons on the toolbar can also be used to zoom in, zoom out and to return to the original view.

By default, the graphics are refreshed automatically when necessary. However, this behaviour can be undesirable if the graphics are very complex. This auto-refresh behavior can be toggled using the View|EnableAutoRefresh and View|DisableAutoRefresh commands. If auto-refresh is disabled, then you can ask to refresh the graphics using the 🖌 button.

It is possible to save a sequence of graphics pages in a metafile (a .MET file) using the File|SaveReplayFile command. This file can later be replayed in *Guide* using the File|ReplayGraphicsFile command.

The graphics currently displayed can be saved in Windows Metafile format (a .WMF file) by using the File|SaveWindowsMetafile command. This .WMF file can subsequently be loaded by another application such as a word processor. An encapsulated PostScript file (a .EPS file) can be created by using the File|CreateEPSFile command. This command creates an .EPS file containing only the visible part of the current graphics page. Parts of the page that are not visible because of the zoom level will be cropped from the .EPS file.

The Edit|Copy command will copy the graphics in Windows Metafile format onto the clipboard.

Graphics pages can be printed by using the File|Print command on *Guide*'s main menu.

CHAPTER 5

ROTORS

All data describing the model is entered in sub-menus of the EDIT menu. Figure 5.1 shows the EDIT menu. In this EDIT menu, and in all sub-menus under it, the QUIT command will take you back to the parent menu after discarding all changes made in the sub-menu and all sub-menus under it. The EXIT command takes you back to the parent without discarding changes.

5.1 Rotors

A *Transmission3D* model is built from three different physical entities: ‘Rotors’, ‘Connectors’ and ‘Housings’.

A ‘rotor’ refer to an entity that rotates about a fixed axis. Each rotor may have a number of concentric external gears, internal gears, carriers and shafts rotating together about the fixed axis. *Transmission3D* does not count bodies that are on moving axes, such as planetary pinions and straight bevel pinions as ’rotors’. These are assigned to the rotor that includes their carrier for the purpose of inputting data. For instance the planetary system shown in Figure 5.2 has 3 rotors. The sun gear, carrier and the ring gear are attached to their respective rotors. The pinions are grouped along with their carrier, and are not assigned a sparate rotor.

The number of rotors in a system is entered in the NROTORS menu in Figure 5.1. Again, the individual pinions are not counted when figuring out the total number of rotors.

5.2 Rotor menu

Click on the ROTOR command in Figure 5.1 to access the the ROTOR menu. The Rotor menu is shown in Fig 5.3. The number of rotors used to model the Planetary system is entered in the NROTORS menu. This number is same as the number you have entered in the NROTORS menu in the EDIT menu (Fig 5.1), and is just redisplayed for convenience.

The data for a rotor can be accessed by typing in its rotor number into the ROTOR item and hitting a return.

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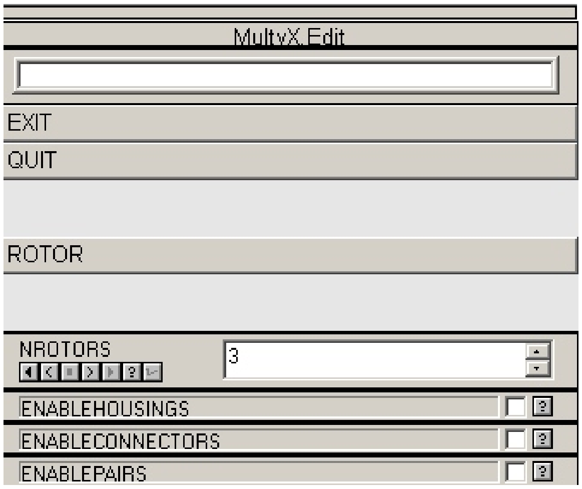

MultyX.Edit
EXIT
QUIT
ROTOR

NROTORS 3

ENABLEHOUSINGS ☐

ENABLECONNECTORS ☐

ENABLEPAIRS ☐

Figure 5.1 The EDIT menu.

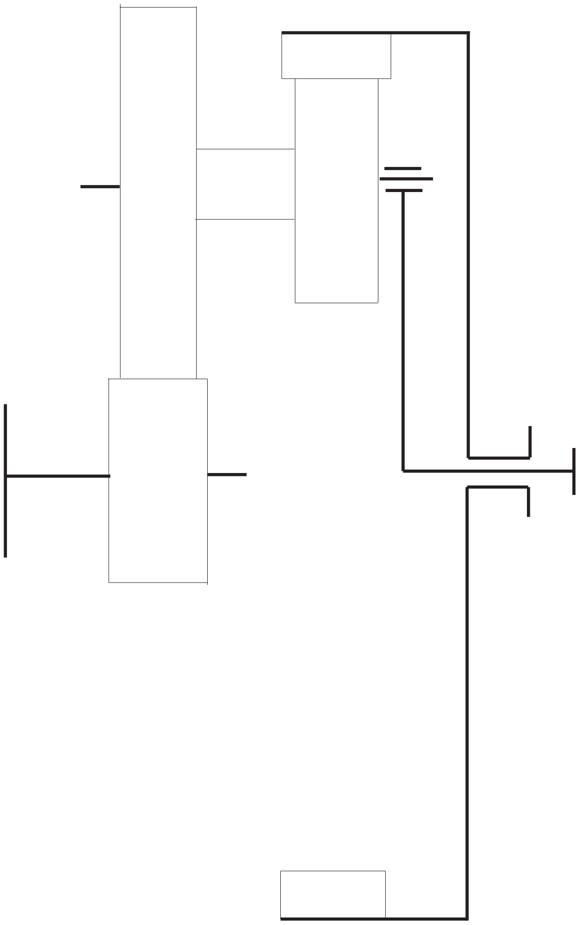
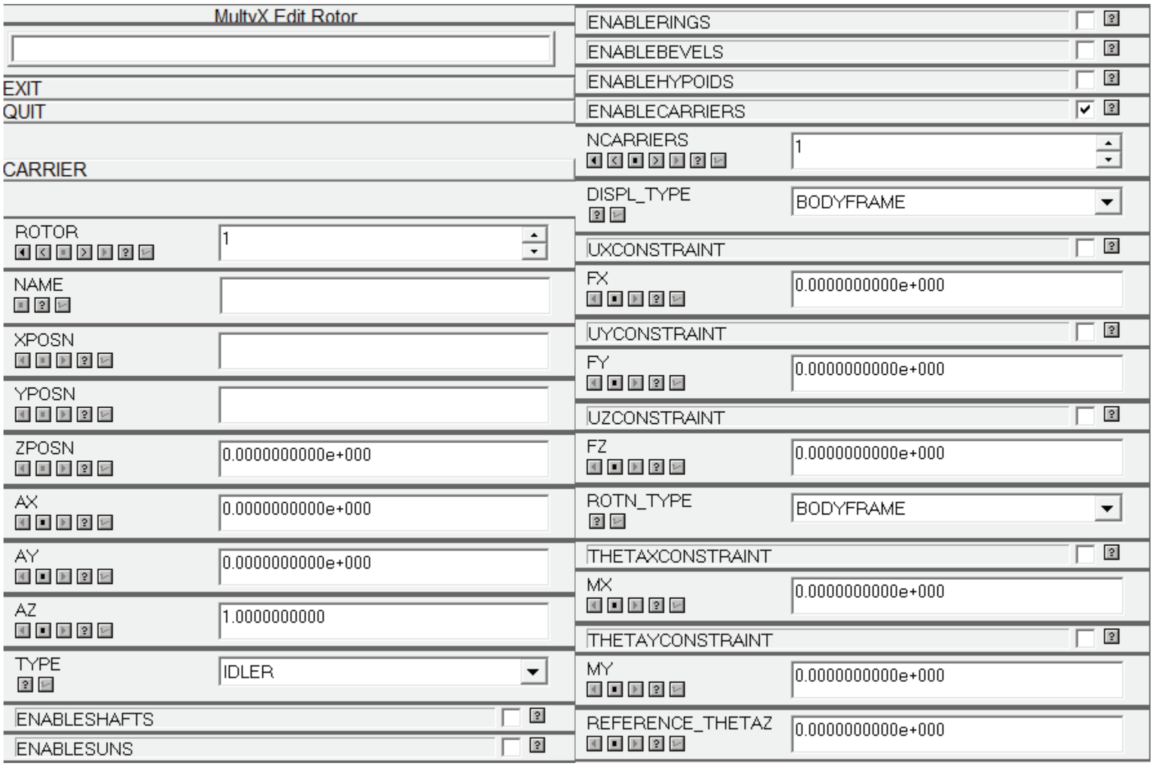


Figure 5.2 A simple planetary system



ROTOR 1

NAME

XPOSN

YPOSN

ZPOSN 0.0000000000e+000

AX 0.0000000000e+000

AY 0.0000000000e+000

AZ 1.0000000000

TYPE IDLER

ENABLESHAFTS ☐

ENABLESUNS ☐

ENABLERINGS ☐

ENABLEBEVELS ☐

ENABLEHYPOIDS ☐

ENABLECARRIERS ☑

NCARRIERS 1

DISPL_TYPE BODYFRAME

UXCONSTRAINT ☐

FX 0.0000000000e+000

UYCONSTRAINT ☐

FY 0.0000000000e+000

UZCONSTRAINT ☐

FZ 0.0000000000e+000

ROTN_TYPE BODYFRAME

THETAXCONSTRAINT ☐

MX 0.0000000000e+000

THETAYCONSTRAINT ☐

MY 0.0000000000e+000

REFERENCE_THETAZ 0.0000000000e+000

Figure 5.3 The Rotor menu.

The first entry in the ROTOR menu is NAME. An alphanumeric name should be assigned to each rotor. The name should have no spaces.

The position in space of the rotor is specified by providing the coordinates of a point on the rotor axis XPOSN, YPOSN, ZPOSN. This point on the rotor axis will be called the ’rotor origin’. The orientation of the rotor axis is specified by providing the components of a unit vector AX, AY and AZ that passes through this point and is oriented along the axis or rotation of the rotor. This orientation vector will be called the ’rotor axis’, or the ’rotor Z axis’. The rotor rotates about this axis.

For each rotor, it is possible to specify either the angular speed, or the externally applied torque. If one is specified, the other must be calculated during analysis. *Transmission3D* classifies all the rotors accordingly. The type of rotor is specified using the TYPE switch. The TYPE of the rotor can be INPUT, OUTPUT, IDLER, INACTIVE or ATTACHEDTOHOUSING. If the INPUT type is selected for the rotor then the rotor input speed is entered in the RPM item. ATTACHEDTOHOUSING rotors are similar to INPUT rotors, but it is assumed that the RPM value associated with them is zero. If the rotor is an OUTPUT member then the externally applied torque load on that rotor is specified in the TORQUE item. IDLER rotors are similar to OUTPUT rotors, but the torque value associated with IDLER rotors is assumed to be zero.

INACTIVE rotors are ignored during analysis, this option is simply provided as a convenient way to ignore rotors whose data has been entered, but are not needed for analysis.

The total number of INPUT members must be equal to the number of degrees of freedom in the system, otherwise the system will be indeterminate. A procedure to calculate the number of input members is described later.

As discussed earlier a rotor may consist of a number of shafts, suns (external helical gears), rings(internal helical gears), straight bevels, hypoids and carriers. You can attach any of these body members to the rotors by turning on the ENABLESHAFTS, ENABLESUNS, ENABLERINGS, ENABLEBEVELS, ENABLEHYPOIDS and ENABLECARRIERS menus respectively in Figure 5.3.

If the ENABLESHAFTS menu is turned on in Figure 5.3, a SHAFT command appears in the Rotor menu as shown in Figure 5.4. The number of shafts attached to the rotor is specified in the NSHAFTS menu. Similarly, if you turn on the ENABLESUNS, ENABLERINGS, ENABLEBEVELS, ENABLEHYPOIDS or ENABLECARRIERS items in Figure 5.3 then Suns, rings, bevels, hypoids and carriers can be attached to the rotor. SUN, RING, BEVEL, HYPOID and CARRIER commands appear on the Rotor menu as shown in Figure 5.4. Their submenus can be accessed by clicking on their respective commands. The number of suns, rings, bevels, hypoids and carriers are specified in the NSUNS, NRINGS, NBEVELS, NHYPOIDS and NCARRIERS menus respectively.

The BODYFRAME displacement type allows you to independently control the 5 linear and angular displacement components within the body reference frame. If you turn on the UXCONSTRAINT flag, the U_x displacement component of the reference frame of the rotor body is constrained. A displacement value can then be specified in the UX item. If it is not turned on then a load value can be specified in the FX item. This prespecified external force is applied on to the reference frame of the rotor body. This force will be transmitted through the parts of the rotor that are constrained to its reference frame. The same thing applies to UYCONSTRAINT, UZCONSTRAINT, THETAXCONSTRAINT and THETAYCONSTRAINT menus. These items are activated only if the rotor type is either INPUT, OUTPUT, IDLER or INACTIVE.

The GLOBALFRAME displacement type allows you to specify the rotor diplacement in the global reference frame, but you can only release or constrain all 3 linear degrees of freedom, and/or both rotational degrees of freedom. The ROTOR menu when this DISPL_TYPE is selected is shown in Figure 5.5.

Tables 5.1 and 5.2 explain all the terms described in the Rotor menu.

5.3 Modeling the Shafts

The SHAFT command in Figure 5.4 leads to the shaft menu shown in Fig 5.6. A rotor can have many shafts. The NSHAFTS item is the number of shafts attached to the rotor. The SHAFT item allows you to select one of these shafts.

The TYPE item selects the type of inputs to be used to build the shaft model. Presently DEFINEGEOMETRY is the only type implemented. A shaft of this type consists of many contiguous ’segments’. The segments of a shaft are numbered along the direction of the rotor axis (Figure 5.7). The axial distance of the start of the first segment from the rotor origin is the AXIALPOSNSHAFT, as shown in Figure 5.7. This value may be positive or negative.

If the UNIFORMMATERIAL flag is turned on, then all the segments in the shaft are assumed to have the same material properties. These material properties are specified through YOUNGSMOD, POISSON, DENSITY, RALEIGHALPHA and RALEIGHBETA. If UNIFORMMATERIAL is turned off, then these material properties are specified individually for each shaft segment in the SEGMENT submenu.

The total number of segments is specified in NSEGMENTS. There should be at least 1 segment. Figure 5.8 shows an example of a rotor with one hypoid and one shaft. The shaft has 8 segments.

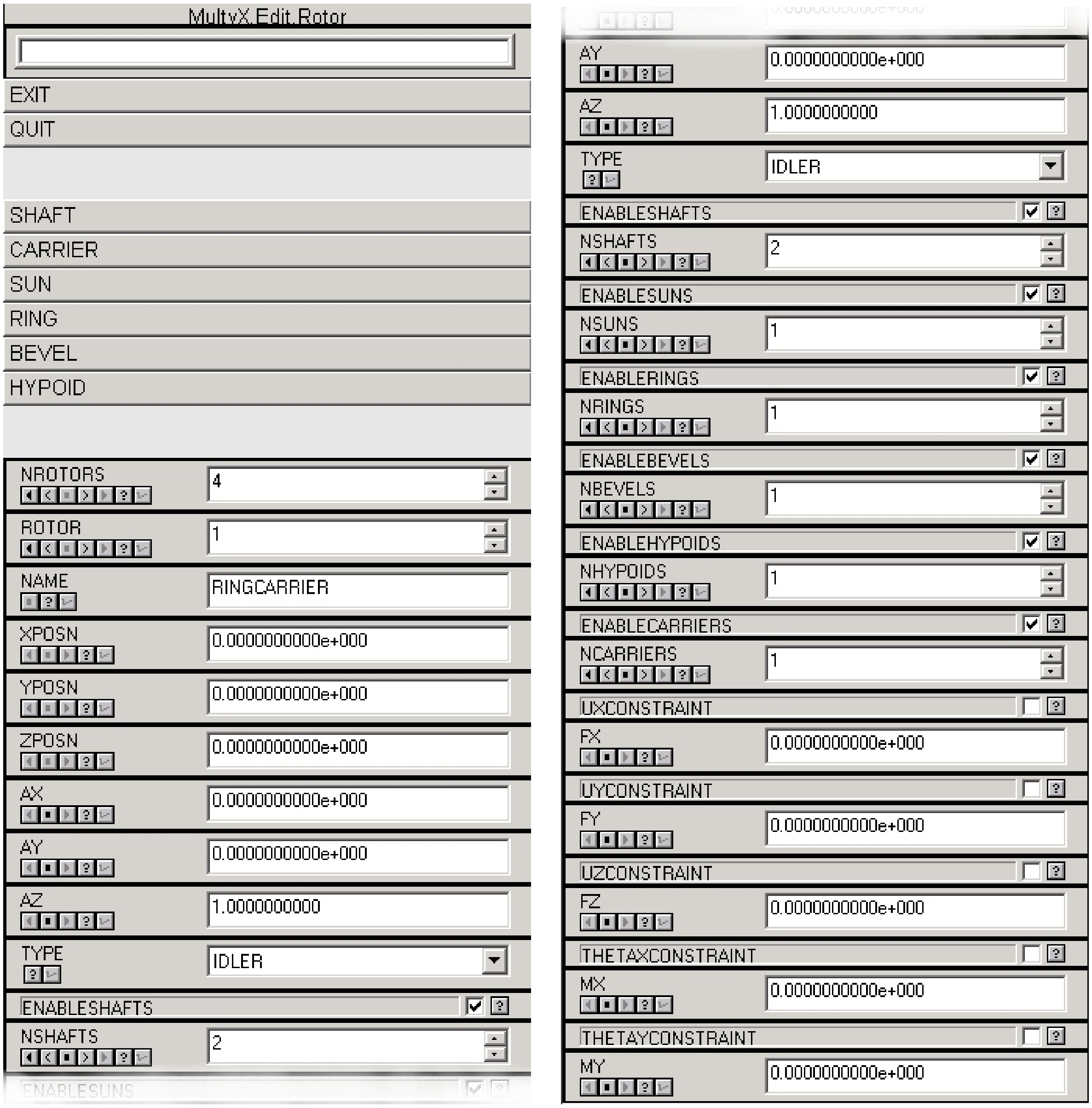
Table 5.3 explains the terms used in the shaft menu.

5.4 Shaft segment

The SEGMENT command in Figure 5.6 leads to the segment menu shown in Figure 5.9. The item NSEGMENTS is the same as in the SHAFT menu, and is repeated for convenience. The SEGMENT item can be used to select the individual segment for which data needs to be entered.

Each shaft segment has a constant inner and outer diameter throughout its length. This length is specified in the LENGTH item. The inner and outer diameter for each segment is specified in the INNERDIA and OUTERDIA menus respectively. The finite element type used for a shaft segment is selected using the ELEMTYPE switch. A segment can be modeled using either the QUADRATIC type elements or CUBIC elements. The number of finite elements in the radial, axial and circumferential directions are controlled by the NRADIAL, NAXIAL and NCIRC menus. In the axial direction if cubic elements are used, then even one element for a segment can model the beam modes of the shaft adequately.

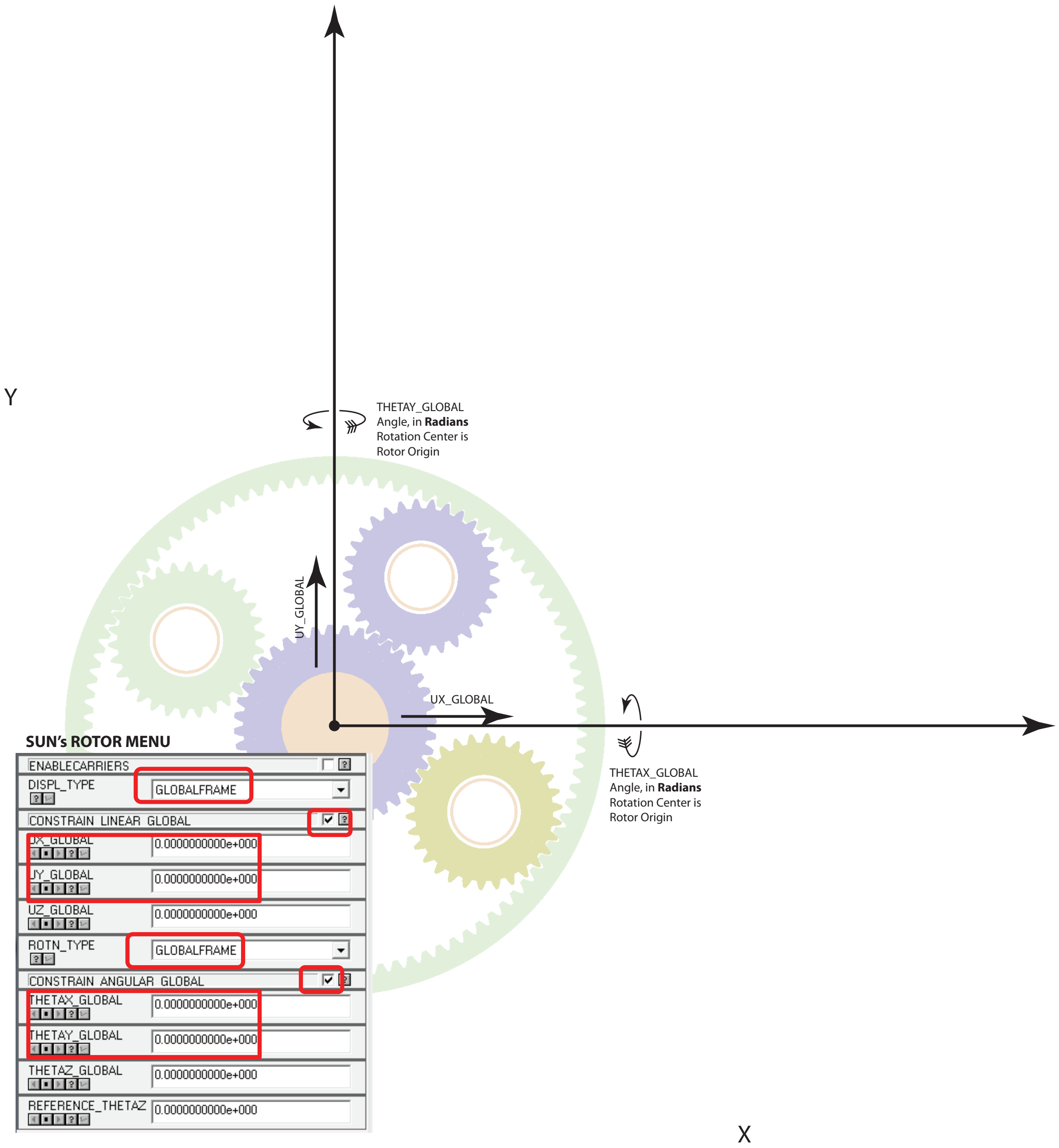
If the ODCONSTRAINED item is turned on, then the outer diameter of that segment is constrained to the rotor reference frame. Similarly, if the IDCONSTRAINED menu in the segment menu is turned on, then the



NROTORS 4
ROTOR 1
NAME RINGCARRIER
XPOSN 0.0000000000e+000
YPOSN 0.0000000000e+000
ZPOSN 0.0000000000e+000
AX 0.0000000000e+000
AY 0.0000000000e+000
AZ 1.0000000000
TYPE IDLER
ENABLESHAFTS ☑
NSHAFTS 2
ENABLESUNS ☑

AY 0.0000000000e+000
AZ 1.0000000000
TYPE IDLER
ENABLESHAFTS ☑
NSHAFTS 2
ENABLESUNS ☑
NSUNS 1
ENABLERINGS ☑
NRINGS 1
ENABLEBEVELS ☑
NBEVELS 1
ENABLEHYPOIDS ☑
NHYPOIDS 1
ENABLECARRIERS ☑
NCARRIERS 1
UXCONSTRAINT ☐
FX 0.0000000000e+000
UYCONSTRAINT ☐
FY 0.0000000000e+000
UZCONSTRAINT ☐
FZ 0.0000000000e+000
THETAXCONSTRAINT ☐
MX 0.0000000000e+000
THETAYCONSTRAINT ☐
MY 0.0000000000e+000

Figure 5.4 The Rotor menu with shaft, sun, ring, bevel, hypoid and carrier options turned on.


Y
THETAY_GLOBAL
Angle, in **Radians**
Rotation Center is
Rotor Origin
UY_GLOBAL
UX_GLOBAL
THETAX_GLOBAL
Angle, in **Radians**
Rotation Center is
Rotor Origin
X

SUN's ROTOR MENU

ENABLECARRIERS	☐
DISPL_TYPE	GLOBALFRAME
CONSTRAIN_LINEAR_GLOBAL	☑
UX_GLOBAL	0.0000000000e+000
UY_GLOBAL	0.0000000000e+000
UZ_GLOBAL	0.0000000000e+000
ROTN_TYPE	GLOBALFRAME
CONSTRAIN_ANGULAR_GLOBAL	☑
THETAX_GLOBAL	0.0000000000e+000
THETAY_GLOBAL	0.0000000000e+000
THETAZ_GLOBAL	0.0000000000e+000
REFERENCE_THETAZ	0.0000000000e+000

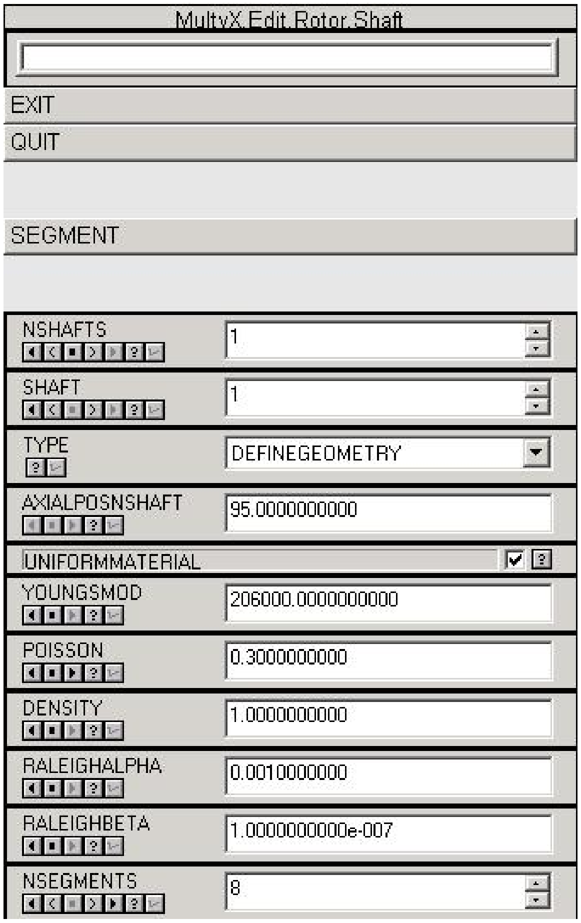
Figure 5.5 The global reference fram displacement type.

Table 5.1 The Rotor menu

Item	Description
NROTORS	Integer, Number of rotors in the system
ROTOR	Integer, Rotor number for the system
NAME	String, Name of the rotor
XPOSN	Float, The X coordinate of the rotor origin
YPOSN	Float, The Y coordinate of the rotor origin
ZPOSN	Float, The Z coordinate of the rotor origin
AX	Float, The X component of the vector that defines the orientation of the rotor Axis.
AY	Float, The Y component of the vector that defines the orientation of the rotor Axis.
AZ	Float, The Z component of the vector that defines the orientation of the rotor Axis.
TYPE	Switch, Type of rotor (choices are INPUT, OUTPUT, IDLER, ATTACHEDTOHOUSING and INACTIVE)
RPM	Float, Angular velocity in RPM for the input rotor (Active if rotor type is INPUT)
TORQUE	Float, The torque at the output rotor (Active if rotor type is OUTPUT)
ENABLESHAFT	Boolean, Whether to allow shafts on the rotor
NSHAFTS	Integer, Number of shafts in a rotor
ENABLESUNS	Boolean, Whether to allow sun gears on the rotor
NSUNS	Integer, Number of suns in a rotor
ENABLERINGS	Boolean, Whether to allow ring gears on the rotor
NRINGS	Integer, Number of rings in a rotor
ENABLEBEVELS	Boolean, Whether to allow bevel gears on the rotor
NBEVELS	Integer, Number of bevels in a rotor

Table 5.2 The Rotor menu (Continued)

Item	Description
ENABLEHYPOIDS	Boolean, Whether to allow hypoid gears on the rotor
NHYPOIDS	Integer, Number of hypoids in a rotor
ENABLECARRIER	Boolean, Whether to allow carriers on the rotor
NCARRIERS	Integer, Number of carriers in a rotor
UXCONSTRAINT	Boolean, Whether the rotor U_x is to be constrained
UX	Float, Specified displacement U_x for the rotor (Active if UXCONSTRAINT = TRUE)
FX	Float, Specified load F_x for the rotor (Active if UXCONSTRAINT = FALSE)
UYCONSTRAINT	Boolean, Whether the rotor U_y is to be constrained
UY	Float, Specified displacement U_y for the rotor (Active if UYCONSTRAINT = TRUE)
FY	Float, Specified load F_y for the rotor (Active if UYCONSTRAINT = FALSE)
UZCONSTRAINT	Boolean, Whether the rotor U_z is to be constrained
UZ	Float, Specified displacement U_z for the rotor (Active if UZCONSTRAINT = TRUE)
FZ	Float, Specified load F_z for the rotor (Active if UZCONSTRAINT = FALSE)
THETAXCONSTRAINT	Boolean, Whether the rotor θ_x is to be constrained
THETAX	Float, Specified displacement θ_x for the rotor (Active if THETAXCONSTRAINT = TRUE)
MX	Float, Specified load M_x for the rotor (Active if MXCONSTRAINT = FALSE)
THETAYCONSTRAINT	Boolean, Whether the rotor θ_y is to be constrained
THETAY	Float, Specified displacement θ_y for the rotor (Active if THETAYCONSTRAINT = TRUE)
MY	Float, Specified load M_y for the rotor (Active if MYCONSTRAINT = FALSE)


MultyX.Edit.Rotor.Shaft
EXIT
QUIT
SEGMENT

NSHAFTS 1

SHAFT 1

TYPE DEFINEGEOMETRY

AXIALPOSNSHAFT 95.0000000000

UNIFORMMATERIAL ☑

YOUNGSMOD 206000.0000000000

POISSON 0.3000000000

DENSITY 1.0000000000

RALEIGHALPHA 0.0010000000

RALEIGHBETA 1.0000000000e-007

NSEGMENTS 8

Figure 5.6 The Shaft menu

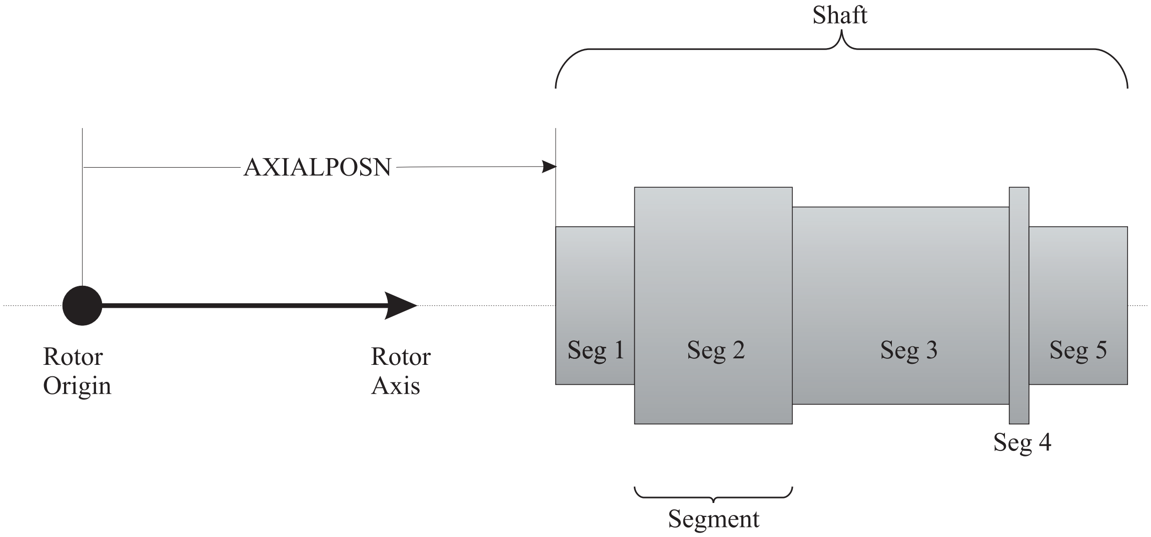

Shaft
AXIALPOSN
Rotor
Origin
Rotor
Axis
Seg 1
Seg 2
Seg 3
Seg 5
Seg 4
Segment

Figure 5.7 Positioning a shaft on a rotor.

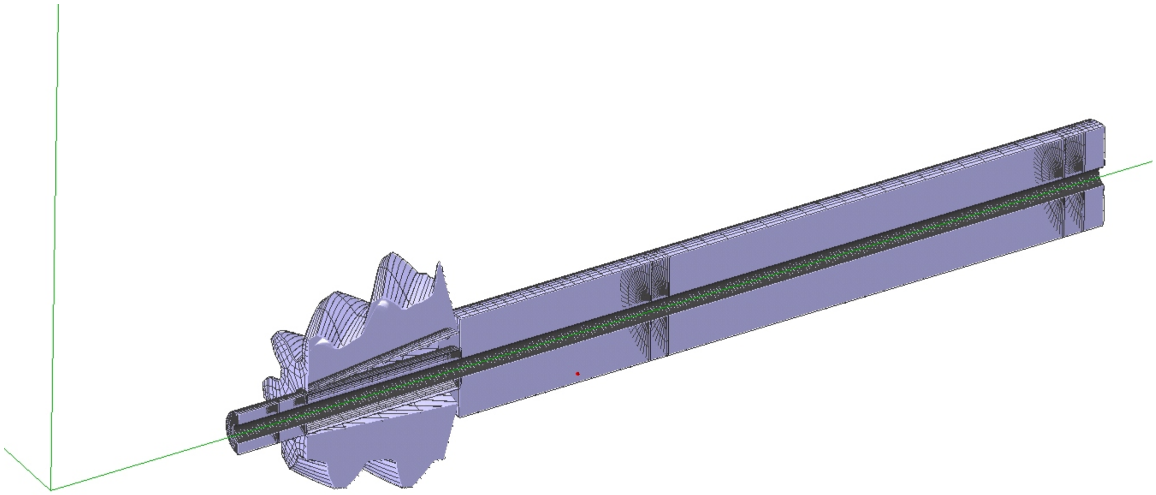


Figure 5.8 A rotor containing one hypoid gear and one shaft with 8 segments

Table 5.3 The Shaft menu

Item	Description
NSHAFTS	Integer, Number of shafts in the rotor
SHAFT	Integer, Shaft number
TYPE	Switch, Type of model to be used for the shaft (Default type is Define Geometry)
ZSHAFT	Float, Z-coordinate for the shaft
UNIFORMGEOMETRY	Boolean, Whether entire shaft has one material
YOUNGSMOD	Float, Young's modulus for the shaft
POISSON	Float, Poisson's ratio for the shaft
DENSITY	Float, Density for the shaft
RAYLEIGHALPHA	Float, Damping constant alpha for the shaft
RAYLEIGHBETA	Float, Damping constant beta for the shaft
NSEGMENTS	Integer, Number of shaft segments

Table 5.4 The Segment menu

Item	Description
NSEGMENTS	Integer, Number of shaft segments
SEGMENT	Integer, Segment number
LENGTH	Float, Length of the shaft segment
TYPE	Switch, Type of model to be used for the shaft
INNERDIA	Float, Inner diameter of the shaft segment
OUTERDIA	Float, Outer diameter of the shaft segment
ELEMTYPE	Switch, Type of finite element used
NRADIAL	Integer, No. of finite elements in the radial direction of the segment
NAXIAL	Integer, No. of finite elements in the axial direction of the segment
NCIRC	Integer, No. of finite elements in the circular direction of the segment
ODCONSTRAINED	Boolean, Whether the OD is constrained
ODRACE	Boolean, Whether the OD is a part of race
CIRCORDEROUTER	Integer, Fourier order in the circular direction
AXIALORDEROUTER	Integer, Fourier order in the axial direction
IDCONSTRAINED	Boolean, Whether the ID is constrained
IDRACE	Boolean, Whether the ID is a part of race
YOUNGSMOD	Float, Young's modulus of the shaft segment
POISSON	Float, Poisson's ratio for the shaft segment
DENSITY	Float, Density of the shaft segment
RAYLEIGHALPHA	Float, Damping constant alpha for the shaft segment
RAYLEIGHBETA	Float, Damping constant beta for the shaft segment

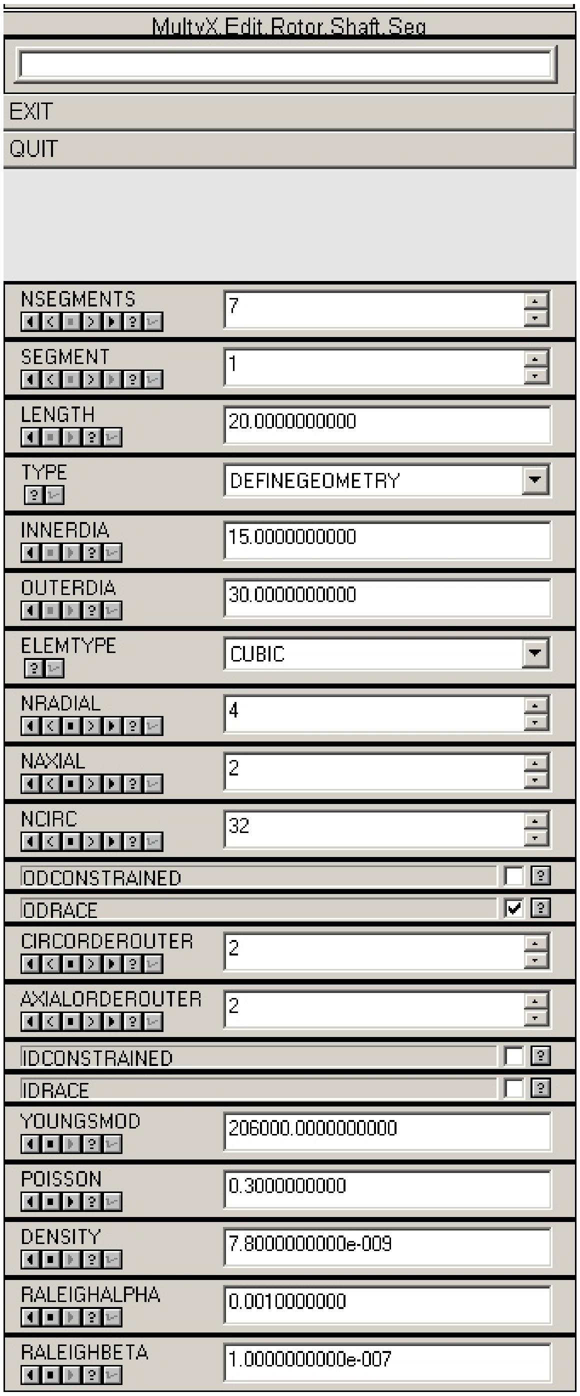
inner diameter of this segment is constrained to the rotor reference frame. Normally the ODCONSTRAINED or the IDCONSTRAINED menu is turned on for a segment if it is connected to the power input or output. Reference frame reaction forces and moments will flow to the shaft through these constraints.

If the ODRACE switch is turned on for a shaft segment, then the outer diameter of this segment can act as a race. A "Race" is a cylindrical surface where the shaft can be connected with other components like bearings, suns, rings and carriers. Similarly, if the IDRACE switch is turned on then inner diameter of this shaft segment acts as a race. The races can be connected to matching races on the bearing, carrier, sun, ring, hypoid, bevel, or even to a race on another shaft of the rotor. Races will be matched only if their diameters are identical and their axial ranges overlap. The order of the Fourier series used for displacement interpolation in the circular direction and the axial direction at the diameter of the shaft segment is controlled by the CIRCORDEROUTER and AXIALORDEROUTER menus respectively.

If the UNIFORMGEOMETRY flag in Figure 5.6 is not checked, then the material properties YOUNGSMOD, POISSON, DENSITY, RALEIGHALPHA and RALEIGHBETA show up in the segment menu, where each segment can be provided its own materal properties. Table 5.4 explains each item used in the segment menu.

5.5 Modeling the Sun and Ring gear

The SUN command in Figure 5.4 leads to the sun gear menu shown in Figure 5.12. The RING command in Figure 5.4 leads to the ring gear menu shown in Figure 5.13. The AXIALPOSN parameter defines the axial position (Z-coordinate) of the gear tooth. This is the distance of the midface cross-section of the gear from



NSEGMENTS 7

SEGMENT 1

LENGTH 20.0000000000

TYPE DEFINEGEOMETRY

INNERDIA 15.0000000000

OUTERDIA 30.0000000000

ELEMTYPE CUBIC

NRADIAL 4

NAXIAL 2

NCIRC 32

ODCONSTRAINED ☐

ODRACE ☑

CIRCORDEROUTER 2

AXIALORDEROUTER 2

IDCONSTRAINED ☐

IDRACE ☐

YOUNGSMOD 206000.0000000000

POISSON 0.3000000000

DENSITY 7.8000000000e-009

RALEIGHALPHA 0.0010000000

RALEIGHBETA 1.0000000000e-007

Figure 5.9 The Segment menu

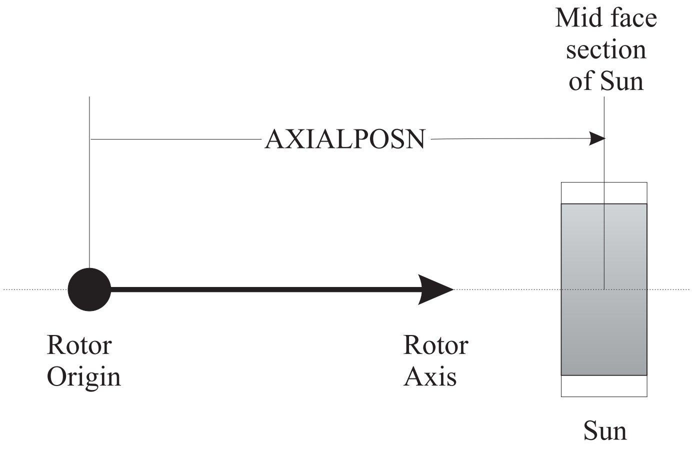

Mid face
section
of Sun
AXIALPOSN
Rotor
Origin
Rotor
Axis
Sun

Figure 5.10 Positioning a sun gear on a rotor.

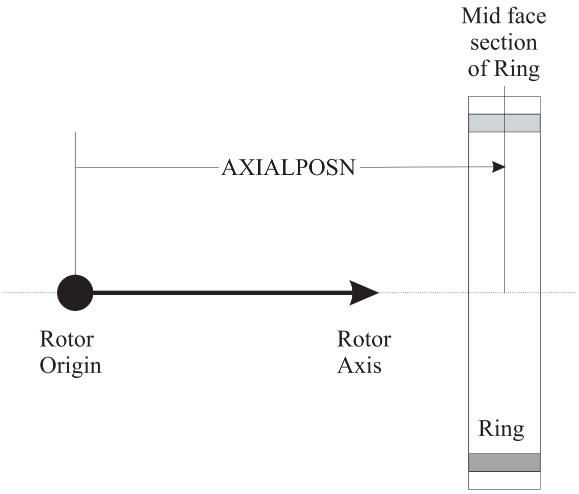
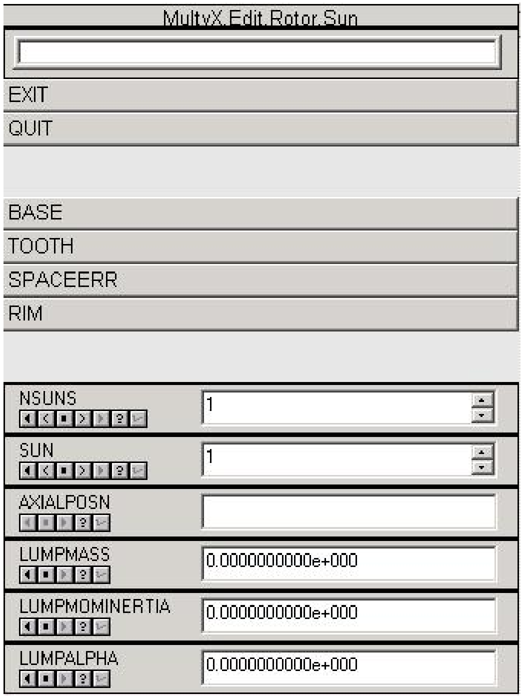

Mid face
section
of Ring
AXIALPOSN
Rotor
Origin
Rotor
Axis
Ring

Figure 5.11 Positioning a ring gear on a rotor.



NSUNS 1

SUN 1

AXIALPOSN

LUMPMASS 0.0000000000e+000

LUMPMOMINERTIA 0.0000000000e+000

LUMPALPHA 0.0000000000e+000

Figure 5.12 The Sun gear menu.

Table 5.5 Sun/Ring lumped parameters

Item	Description
LUMPMASS	Float, Lumped mass added at the center of the sun/ring in addition to the mass of the tooth and rim model
LUMPMOMINERTIA	Float, Lumped polar moment of inertia J_z added at the center of the sun/ring in addition to the J_z of the tooth and rim model
LUMPALPHA	Float, The damping constant for the lumped mass and moment of inertia

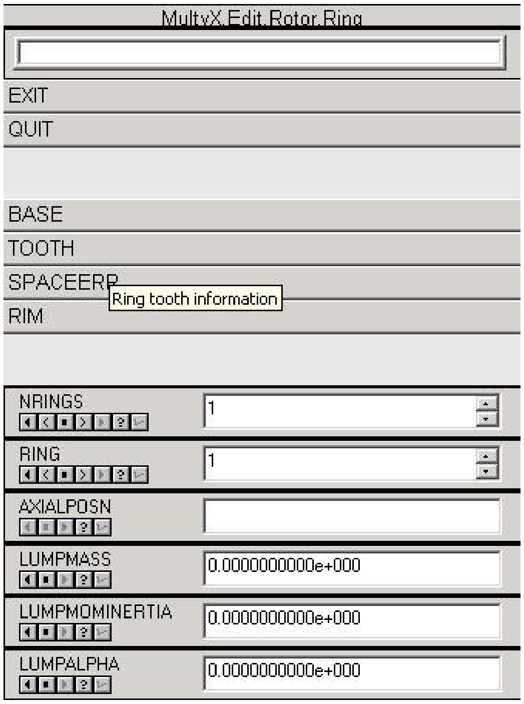
the rotor origin, measured along the rotor axis, as shown in Figures 5.10 and 5.11. It may be either positive or negative. The number of suns or rings attached to a rotor is entered in NSUNS or NRINGS, respectively. The sun and the ring lumped parameters are explained in Table 5.5.

There are 4 submenus (BASE, SPACEERR, TOOTH and RIM) under the sun and RING menus, as shown in Figure 5.12 and Figure 5.13.

5.5.1 Sun and ring gear base

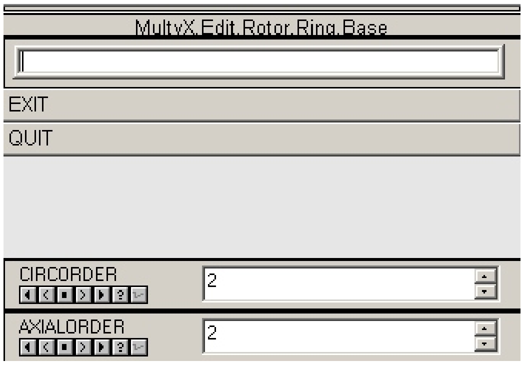
The BASE command in Figure 5.12 leads to the sun gear base menu shown in Figure 5.14. The ring gear base menu is same as that of the sun.

The sun or ring gear base is the cylindrical surface where the gear can be attached to a shaft, carrier, or another gear in the rotor. It can also attach to a ’connector’. At this cylindrical surface, the finite element nodal degrees of freedom are replaced by the coefficients of fourier series in the circular direction and a


MultyX.Edit.Rotor.Ring
EXIT
QUIT
BASE
TOOTH
SPACEERR
RIM
Ring tooth information

NRINGS 1
RING 1
AXIALPOSN
LUMPMASS 0.0000000000e+000
LUMPMOMINERTIA 0.0000000000e+000
LUMPALPHA 0.0000000000e+000

Figure 5.13 The Ring gear menu.


MultyX.Edit.Rotor.Ring.Base
EXIT
QUIT

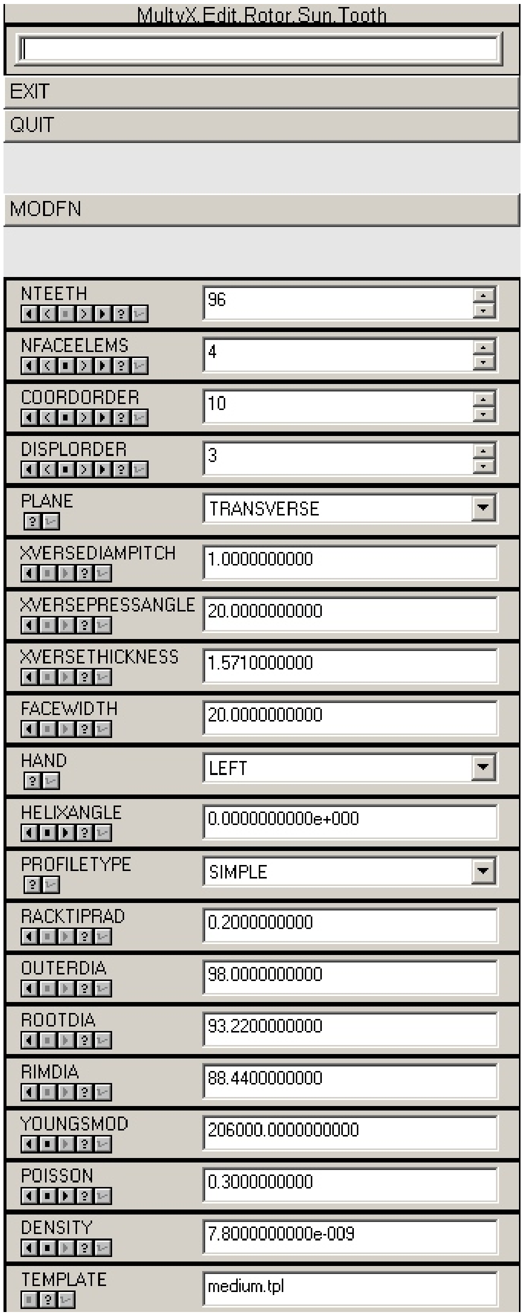
CIRCORDER 2
AXIALORDER 2

Figure 5.14 The Sun gear base menu.

polynomial series in the axial direction. The circular order and the axial order of the fourier series are CIRCORDER and AXIALORDER, respectively. The CIRCORDER and AXIALORDER values for the base of the gear should be equal to the corresponding values applied at the races of all other shafts, gears and connectors which attach to it.

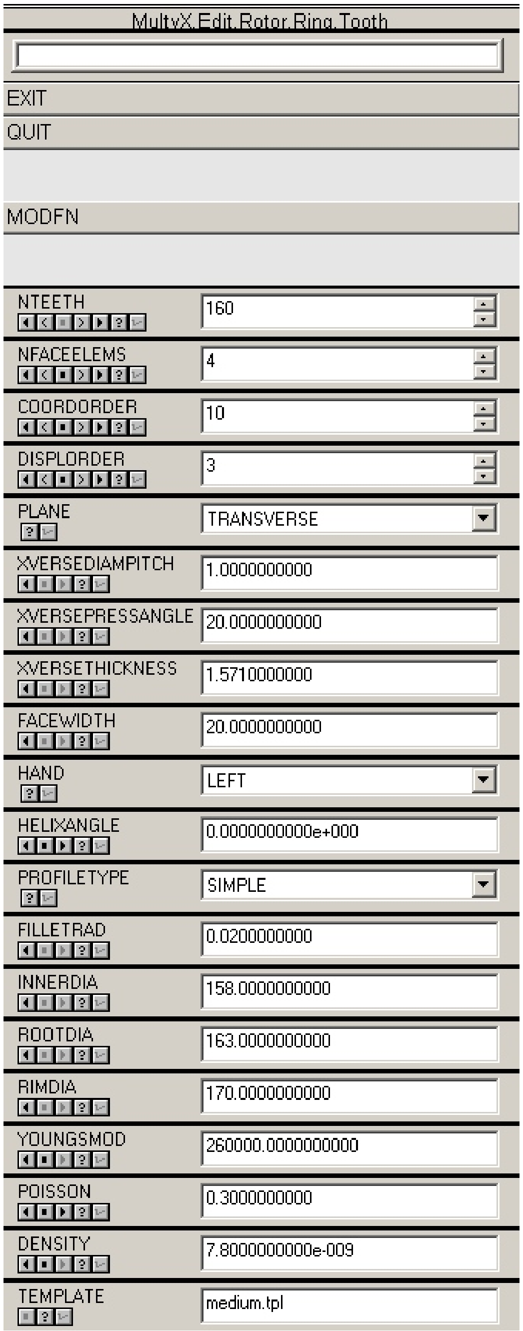
5.5.2 Modeling the tooth profile for sun and ring

The TOOTH command in Figures 5.12 and 5.13 leads to the tooth data menu for the sun and ring gear respectively. Figure 5.15 shows the Sun tooth menu and Figure 5.16 shows the Ring tooth menu. Table 5.6 describes the parameters common to the sun and ring tooth menus. Table 5.7 describes the parameters specific to the sun tooth menu and Table 5.8 describes the parameters specific to the ring tooth menu.



NTEETH	96
NFACEELEMS	4
COORDORDER	10
DISPLORDER	3
PLANE	TRANSVERSE
XVERSEDIAMPITCH	1.0000000000
XVERSEPRESSANGLE	20.0000000000
XVERSETHICKNESS	1.5710000000
FACEWIDTH	20.0000000000
HAND	LEFT
HELIXANGLE	0.0000000000e+000
PROFILETYPE	SIMPLE
RACKTIPRAD	0.2000000000
OUTERDIA	98.0000000000
ROOTDIA	93.2200000000
RIMDIA	88.4400000000
YOUNGSMOD	206000.0000000000
POISSON	0.3000000000
DENSITY	7.8000000000e-009
TEMPLATE	medium.tpl

Figure 5.15 The tooth data menu for the sun gear.



NTEETH	160
NFACEELEMS	4
COORDORDER	10
DISPLORDER	3
PLANE	TRANSVERSE
XVERSEDIAMPITCH	1.0000000000
XVERSEPRESSANGLE	20.0000000000
XVERSETHICKNESS	1.5710000000
FACEWIDTH	20.0000000000
HAND	LEFT
HELIXANGLE	0.0000000000e+000
PROFILETYPE	SIMPLE
FILLETRAD	0.0200000000
INNERDIA	158.0000000000
ROOTDIA	163.0000000000
RIMDIA	170.0000000000
YOUNGSMOD	260000.0000000000
POISSON	0.3000000000
DENSITY	7.8000000000e-009
TEMPLATE	medium.tpl

Figure 5.16 The tooth data menu for the ring gear.

Table 5.6 Parameters common to sun and ring teeth

Item	Description	Condition
NTEETH	Integer, The number of teeth on gear	
NFACEELEMS	Integer, The number of elements across face	
COORDORDER	Integer, Limit on order of coord axodes	
DISPLORDER	Integer, Limit on displ. order of axodes.	
PLANE	Switch, The plane used to define DP., P.A. and thickness. This switch can be set to one of the two options: NORMAL or TRANSVERSE	
NORMALDIAMPITCH	Float, The normal gen. diametral pitch	if(PLANE=NORMAL)
NORMALPRESSANGLE	Float, The normal gen. press. angle (Deg)	if(PLANE=NORMAL)
NORMALTHICK	Float, Normal thickness of the gear tooth	if(PLANE=NORMAL)
XVERSEDIAMPITCH	Float, The xverse gen. diametral pitch	if(PLANE≠NORMAL)
XVERSEPRESSANGLE	Float, The xverse gen. press. angle (Deg)	if(PLANE≠NORMAL)
XVERSETHICKNESS	Float, Transverse thickness of the gear tooth	if(PLANE≠NORMAL)
FACEWIDTH	Float, The face width of the gear	
HAND	Switch, The hand of the gear (Left/Right)	
HELIXANGLE	Float, The helix angle of the gear	
ROOTDIA	Float, Root dia.of the gear	
RIMDIA	Float, Rim diameter of the gear	if(RIMTYPE=NONE)
YOUNGSMOD	Float, Young’s modulus for the gear	
POISSON	Float, Poisson’s ratio for the gear	
DENSITY	Float, Density for the gear	
TPLFILE	String, Template file name for gear	

Table 5.7 Parameters for defining an sun tooth

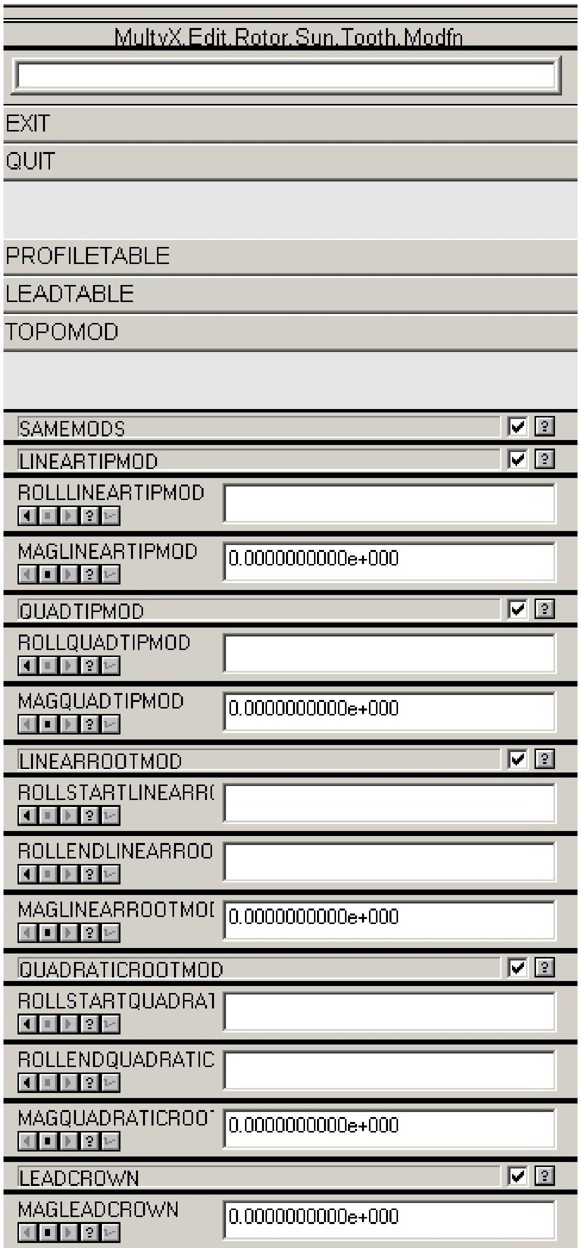
Item	Description	Condition
RACKTIPRAD	Float, Rack tip radius for the gear	
OUTERDIA	Float, Outer dia. of the gear	
INNERDIA	Float, Inner dia. of the gear	if(RIMTYPE = NONE)

Table 5.8 Parameters for defining ring tooth

Item	Description	Condition
FILLETRAD	Float, Fillet radius for the gear	
INNERDIA	Float, Inner dia. of the gear	
OUTERDIA	Float, Outer dia. of the gear	if(RIMTYPE = NONE)

5.5.3 Surface modifications

The MODFN command in the tooth data menus (Figures 5.15 and 5.16) leads to the menu shown in Figure 5.17. This menu is used to specify surface modifications. Five simple surface modifications can be specified directly in this menu: linear and quadratic tip relief, linear and quadratic root relief and crown lead modification. If the SAMEMODS item is checked, then the same modifications is applied on both sides of the tooth.


MultyX.Edit.Rotor.Sun.Tooth.Modfn
EXIT
QUIT
PROFILETABLE
LEADTABLE
TOPOMOD

SAMEMODS ☑
LINEARTIPMOD ☑
ROLLLINEARTIPMOD
MAGLINEARTIPMOD 0.0000000000e+000
QUADTIPMOD ☑
ROLLQUADTIPMOD
MAGQUADTIPMOD 0.0000000000e+000
LINEARROOTMOD ☑
ROLLSTARTLINEARR
ROLLENDLINEARROO
MAGLINEARROOTMO 0.0000000000e+000
QUADRATICROOTMOD ☑
ROLLSTARTQUADRA
ROLLENDQUADRATIC
MAGQUADRATICROO 0.0000000000e+000
LEADCROWN ☑
MAGLEADCROWN 0.0000000000e+000

Figure 5.17 The tooth modification menu.

Linear tip relief is applied using the parameters shown in Table 5.9 and Figure 5.18. The modification magnitude is a linear function of the involute roll angle.

Table 5.9 Linear tip modification parameters

Item	Description
LINEARTIPMOD	Boolean, Whether to apply the linear tip modfn.
ROLLLINEARTIPMOD	Float, Roll angle at start of the linear tip modfn.
MAGLINEARTIPMOD	Float, Magnitude of the linear tip modfn.

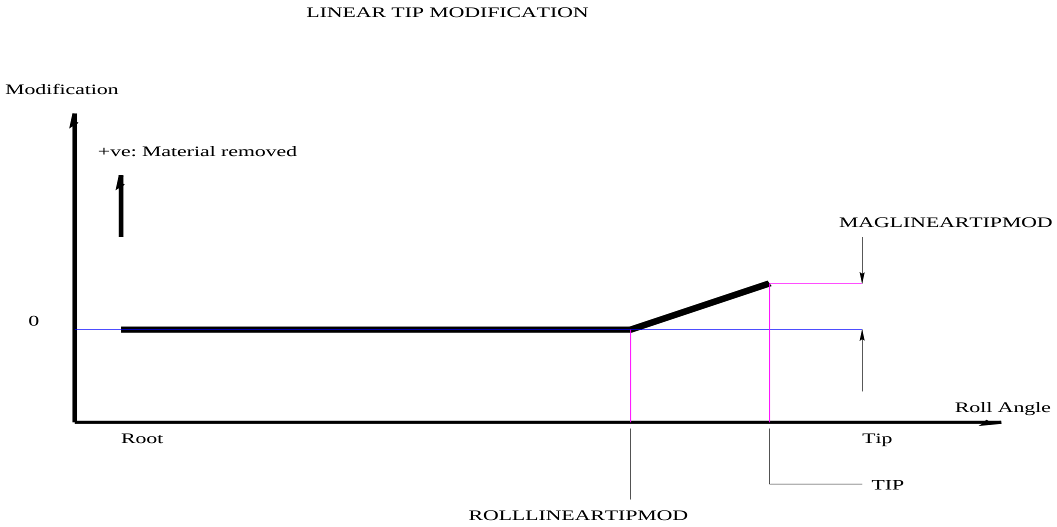

LINEAR TIP MODIFICATION
Modification
+ve: Material removed
MAGLINEARTIPMOD
0
Roll Angle
Root
Tip
TIP
ROLLLINEARTIPMOD

Figure 5.18 Linear tip modification

Linear root relief is applied using the parameters shown in Table 5.10 and Figure 5.19. The modification magnitude is a linear function of the involute roll angle.

Table 5.10 Linear root modification parameters

Item	Description
LINEARROOTMOD	Boolean, Whether to apply the linear flank modfn.
ROLLSTARTLINEARROOTMOD	Float, Roll angle at start of the linear flank modfn.
ROLLENDLINEARROOTMOD	Float, Roll angle at the end of the linear flank modfn.
MAGLINEARROOTMOD	Float, Magnitude of the linear flank modfn.

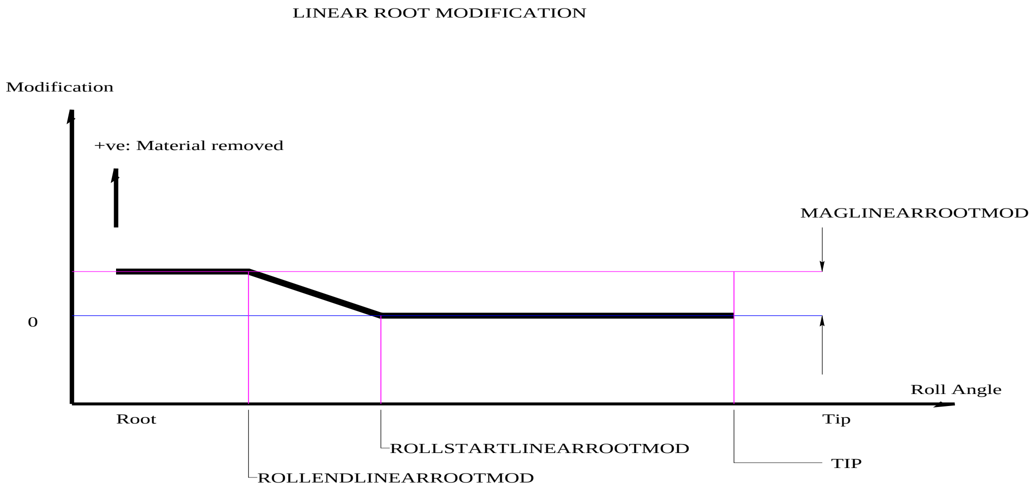

LINEAR ROOT MODIFICATION
Modification
+ve: Material removed
MAGLINEARROOTMOD
0
Roll Angle
Root
Tip
ROLLSTARTLINEARROOTMOD
TIP
ROLLENDLINEARROOTMOD

Figure 5.19 Linear root modification

Quadratic tip relief is applied using the parameters shown in Table 5.11 and Figure 5.20. The modification magnitude is a quadratic function of the involute roll angle.

Table 5.11 Quadratic tip modification parameters

Item	Description
QUADTIPMOD	Boolean, Whether to apply the quadratic tip modfn.
ROLLQUADTIPMOD	Float, Roll angle at start of the quadratic tip modfn.
MAGQUADTIPMOD	Float, Magnitude of the quadratic tip modfn.

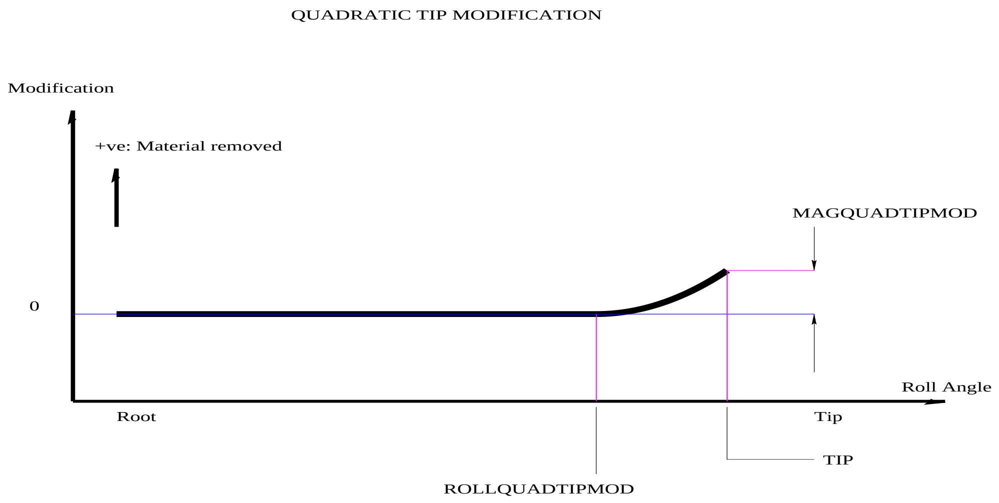

QUADRATIC TIP MODIFICATION
Modification
+ve: Material removed
MAGQUADTIPMOD
0
Roll Angle
Root
Tip
TIP
ROLLQUADTIPMOD

Figure 5.20 Quadratic tip modification

Quadratic root relief is applied using the parameters shown in Table 5.12 and Figure 5.21. The modification magnitude is a quadratic function of the involute roll angle.

Table 5.12 Quadratic root modification parameters

Item	Description
QUADROOTMOD	Boolean, Whether to apply the quadratic flank modfn.
ROLLSTARTQUADROOTMOD	Float, Roll angle at start of the quadratic flank modfn.
ROLLENDQUADROOTMOD	Float, Roll angle at the end of the quadratic flank modfn.
MAGQUADROOTMOD	Float, Magnitude of the quadratic root modfn.

Table 5.13 Crown modification parameters

Item	Description
LEADCROWN	Boolean, Whether to apply the lead crowning.
MAGLEADCROWN	Float, Magnitude of the lead crown.

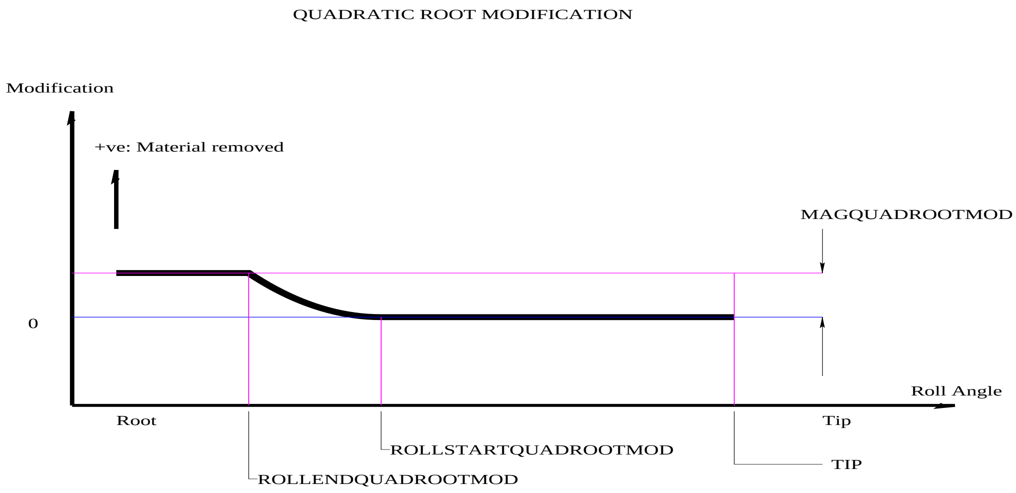

QUADRATIC ROOT MODIFICATION
Modification
+ve: Material removed
MAGQUADROOTMOD
0
Roll Angle
Root
Tip
ROLLSTARTQUADROOTMOD
TIP
ROLLENDQUADROOTMOD

Figure 5.21 Quadratic root modification

Crown modifcation is applied using the parameters shown in Table 5.13 and Figure 5.22. The modification magnitude is a quadratic function the surface coordinate ζ. ζ varies from -1 to $+1$ along the face width of the tooth.

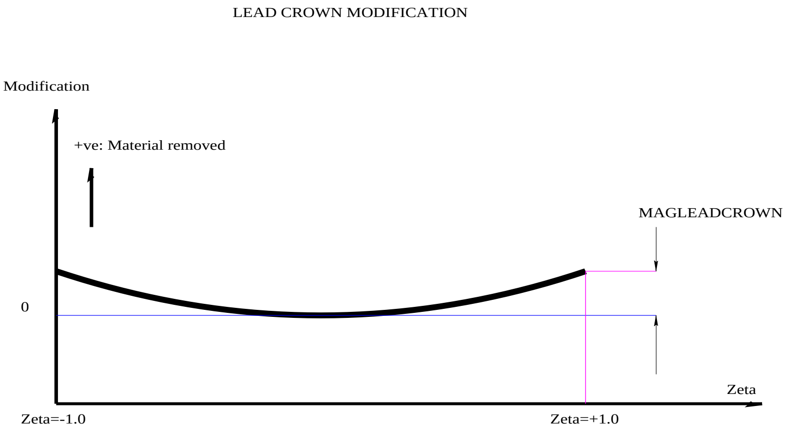
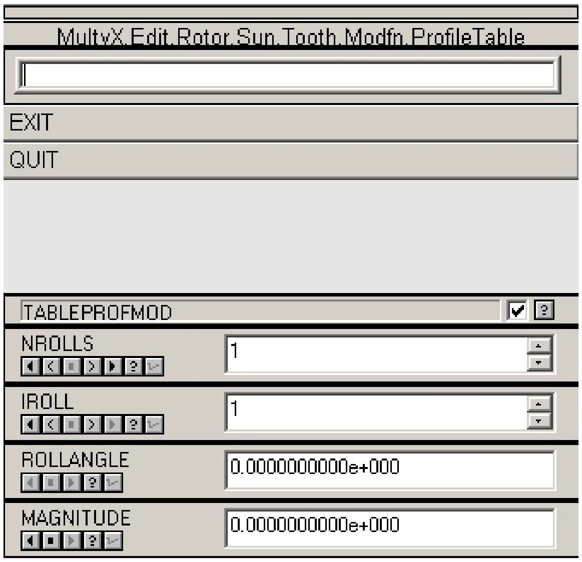

LEAD CROWN MODIFICATION
Modification
+ve: Material removed
MAGLEADCROWN
0
Zeta
Zeta=-1.0
Zeta=+1.0

Figure 5.22 Crown modification

The PROFILETABLE command in the tooth data menu of Figure 5.17 leads to the menu shown in Figure 5.23. This menu is used to specify an arbitrary profile modification in tabular form. Table 5.14 and Figure 5.24 show the meaning of the parameters in this menu. The modification is specified at an arbitrary number of roll angle values. In between these roll angle values, the profile modification is linearly interpolated.


MultyX.Edit.Rotor.Sun.Tooth.Modfn.ProfileTable
EXIT
QUIT

TABLEPROFMOD ☑

NROLLS 1

IROLL 1

ROLLANGLE 0.0000000000e+000

MAGNITUDE 0.0000000000e+000

Figure 5.23 The tabular profile modifications menu.

Similarly, an arbitrary lead modification can be specified in tabular form. The LEADTABLE command in the tooth data menu of Figure 5.17 leads to the menu shown in Figure 5.25. Table 5.15 and Figure 5.26 show the meaning of the parameters in this menu. The modification is specified at an arbitrary number of ζ values. The surface coordinate ζ varies from -1 to $+1$ along the face width of the tooth. In between these ζ values, the lead modification is linearly interpolated.

Table 5.14 Tabular profile modification parameters

Item	Description
TABLEPROFMOD	Boolean, Whether to use a profile modfn table.
NROLLS	Integer, The number of roll angles used in the profile modfn. table
IROLL	Integer, The roll angle number in the profile modfn. table
ROLLANGLE	Float, Vector, indexed by IROLL, Roll angle in the profile modfn. table
MAGNITUDE	Float, Vector, indexed by IROLL, Magnitude of modification in the profile modfn. table

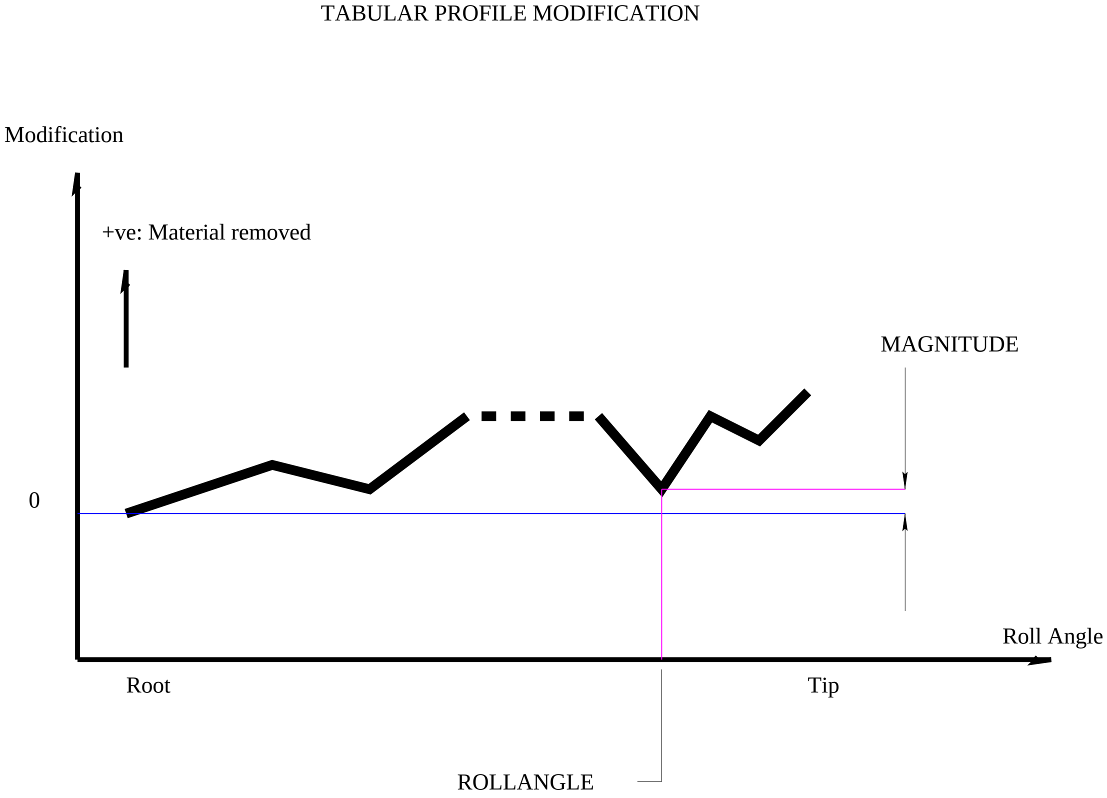
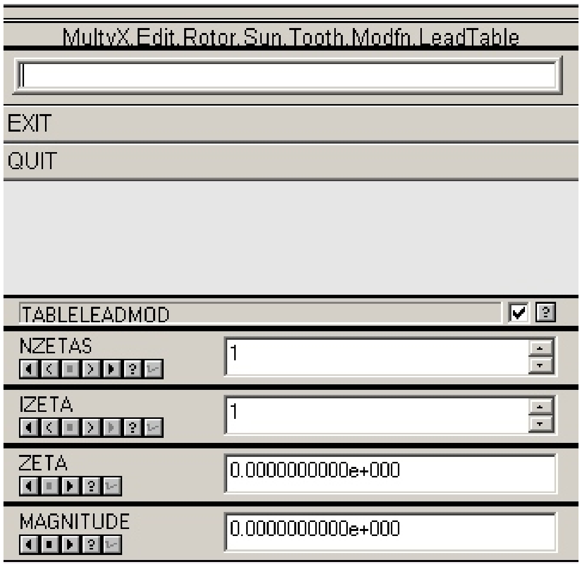

TABULAR PROFILE MODIFICATION
Modification
+ve: Material removed
MAGNITUDE
0
Roll Angle
Root
Tip
ROLLANGLE

Figure 5.24 Tabular tip modification

Finally, a surface modification that is an arbitrary function of both the roll angle and ζ can be specified using the topographic modification option. The TOPOMOD command in the tooth data menu of Figure 5.17 leads to the menu shown in Figure 5.27. Table 5.16 shows the meaning of the parameters in this menu. The modification is specified at an arbitrary number of ζ and roll angle values. The magnitude is specified for each pair of these values. Bilinear interpolation is used between them.



TABLELEADMOD ☑

NZETAS 1

IZETA 1

ZETA 0.0000000000e+000

MAGNITUDE 0.0000000000e+000

Figure 5.25 The tabular lead modifications menu.

Table 5.15 Tabular lead modification parameters

Item	Description
TABLELEADMOD	Boolean, Whether to use a lead modfn table.
NZETAS	Integer, The number zetas used in the lead modfn. table
IZETA	Integer, The zeta number in the lead modfn. table
ZETA	Float, Vector indexed by IZETA, Zeta value in the lead modfn. table
MAGNITUDE	Float, Vector indexed by IZETA, Magnitude of modification in the lead modfn. table

5.5.4 Tooth numbering

Each individual tooth of the sun and ring gear is assigned a tooth number. Figures 5.28 and 5.29 show the numbering schemes used for external and internal gears, respectively. In these figures, the Z axis is pointing out of the plane of the drawing.

Additionally, the two sides of each tooth are also labeled, SIDE1 and SIDE2 as shown in Figures 5.28 and 5.29.

5.5.5 Spacing errors for sun/ring gear

The SPACEERR command in Figures 5.12 and 5.13 leads to the spacing error menu shown in 5.30. The spacing error is an angular amount by which the two surfaces of individual teeth on the sun/ring gear can be rotated from their nominal positions. A positive rotation always follows the right hand rule about the Z axis. The spacing error can be entered for any tooth in this menu.

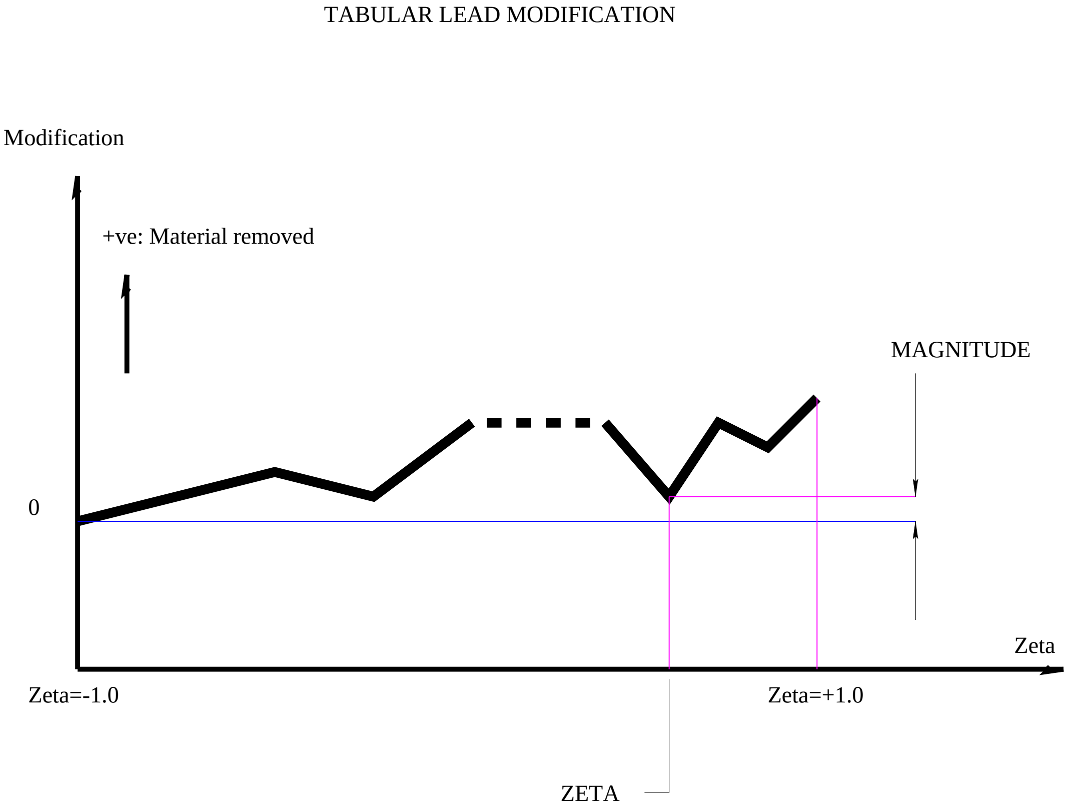

TABULAR LEAD MODIFICATION
Modification
+ve: Material removed
MAGNITUDE
0
Zeta
Zeta=-1.0
Zeta=+1.0
ZETA

Figure 5.26 Tabular lead modification

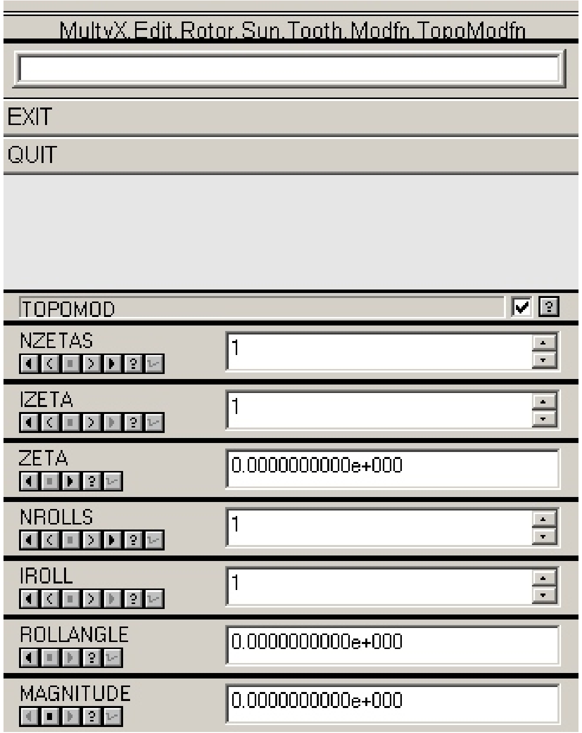
5.5.6 Modeling the Rim

The purpose of including a rim model is to apply the correct boundary condition to the tooth model. This is important because the boundary conditions can have a significant effect on the load and stress distribution [17].

The RIM command in Figures 5.12 and 5.13 leads to the rim data menu shown in Figure 5.31. The default rim type is NONE. For this default case, no data is necessary.

The other rim options are SIMPLE and WEBBED.

Figure 5.32 shows the sun and ring gear rim menus as they appear for the SIMPLE rim. Table 5.17 and Figures 5.33 and 5.34 explain the meaning of the input parameters.



MultyX.Edit.Rotor.Sun.Tooth.Modfn.TopoModfn

EXIT

QUIT

TOPOMOD ☑

NZETAS 1

IZETA 1

ZETA 0.0000000000e+000

NROLLS 1

IROLL 1

ROLLANGLE 0.0000000000e+000

MAGNITUDE 0.0000000000e+000

Figure 5.27 The topographical modifications menu.

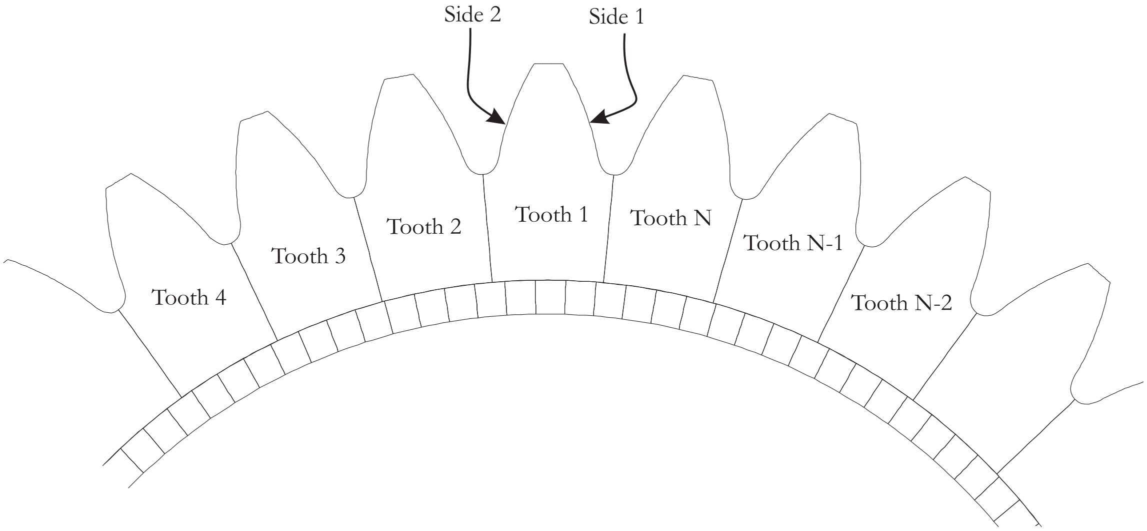

Side 2
Side 1
Tooth 4
Tooth 3
Tooth 2
Tooth 1
Tooth N
Tooth N-1
Tooth N-2

Figure 5.28 The tooth and side numbering scheme for the sun gear

Table 5.16 Topographical surface modification parameters

Item	Description
TOPOMOD	Boolean, Whether to use topographic modfns.
NZETAS	Integer, The number zetas used in the topographic modfn. table
IZETA	Integer, The zeta number in the topo modfn. table
ZETA	Float, Vector indexed by Zeta value in the topo. modfn. table
NROLLS	Integer, The number roll angles used in the topo. modfn. table
IROLL	Integer, The roll angle number in the topo. modfn. table
ROLL	Float, Vector indexed by IROLL, Roll angle in the topo. modfn. table
MAGNITUDE	Float, Array indexed by IZETA and IROLL, Magnitude of modification in the topo. modfn.

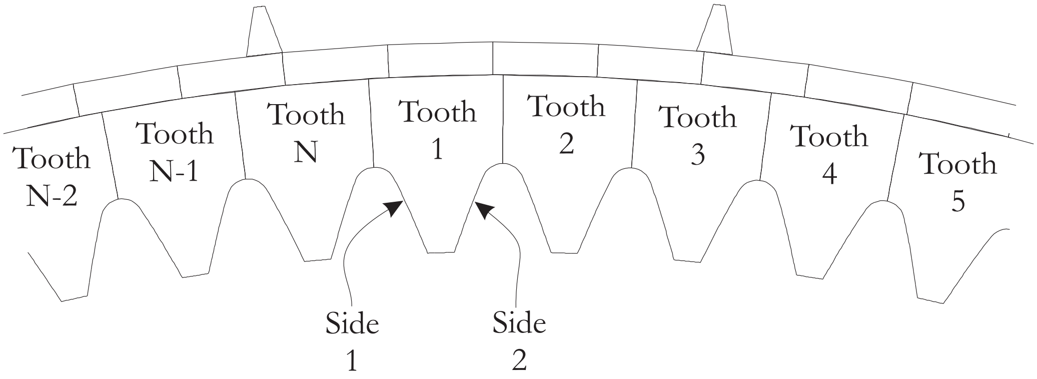
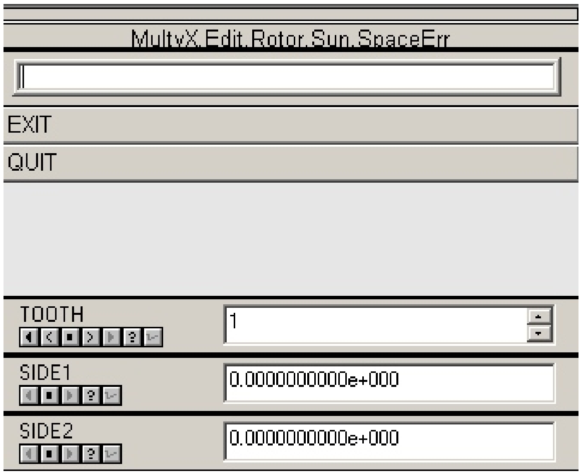


Figure 5.29 The tooth and side numbering scheme for an ring gear

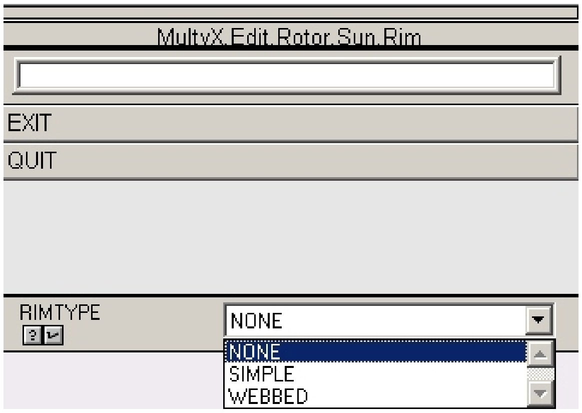

MultyX.Edit.Rotor.Sun.SpaceErr
EXIT
QUIT

TOOTH 1

SIDE1 0.0000000000e+000

SIDE2 0.0000000000e+000

Figure 5.30 The spacing error menu.

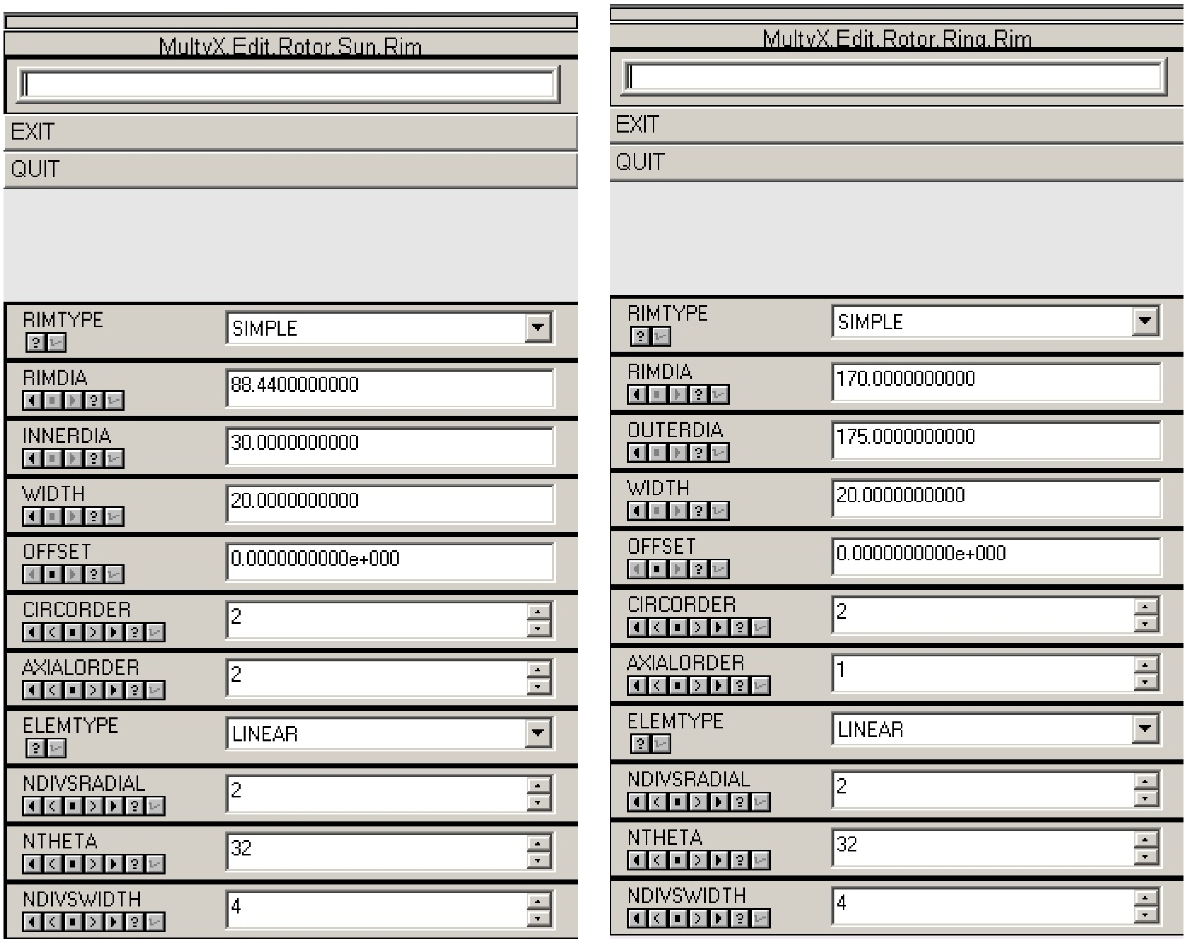

MultyX.Edit.Rotor.Sun.Rim
EXIT
QUIT
NONE
SIMPLE
WEBBED

RIMTYPE NONE

Figure 5.31 The menu for specifying rim data.

Table 5.17 Simple rim parameters

Item	Description	Condition
RIMDIA	Float, Rim diameter of the gear	
INNERDIA	Float, Inner dia. of the gear	only for sun gear
OUTERDIA	Float, Outer dia. of the gear	only for ring gear
WIDTH	Float, Width in the axial direction of rim.	
OFFSET	Float, Offset in the axial direction of rim.	
CIRCORDER	Integer, Fourier series order in the circular direction	
AXIALORDER	Integer, Polynomial order in the face direction	
ELEMTYPE	Switch, Type of finite element. Available options are LINEAR, QUADRATIC and CUBIC	
NDIVSRADIAL	Integer, Number of elements in the radial direction	
NTHETA	Integer, Number of elements in the circular direction	
NDIVSWIDTH	Integer, Number of elements in the axial direction	


MultyX.Edit.Rotor.Sun.Rim
EXIT
QUIT
MultyX.Edit.Rotor.Ring.Rim
EXIT
QUIT

RIMTYPE	SIMPLE
RIMDIA	88.4400000000
INNERDIA	30.0000000000
WIDTH	20.0000000000
OFFSET	0.0000000000e+000
CIRCORDER	2
AXIALORDER	2
ELEMTYPE	LINEAR
NDIVSRADIAL	2
NTHETA	32
NDIVSWIDTH	4

RIMTYPE	SIMPLE
RIMDIA	170.0000000000
OUTERDIA	175.0000000000
WIDTH	20.0000000000
OFFSET	0.0000000000e+000
CIRCORDER	2
AXIALORDER	1
ELEMTYPE	LINEAR
NDIVSRADIAL	2
NTHETA	32
NDIVSWIDTH	4

(a) Sun gear

(b) Ring gear

Figure 5.32 The menu for a simple rim

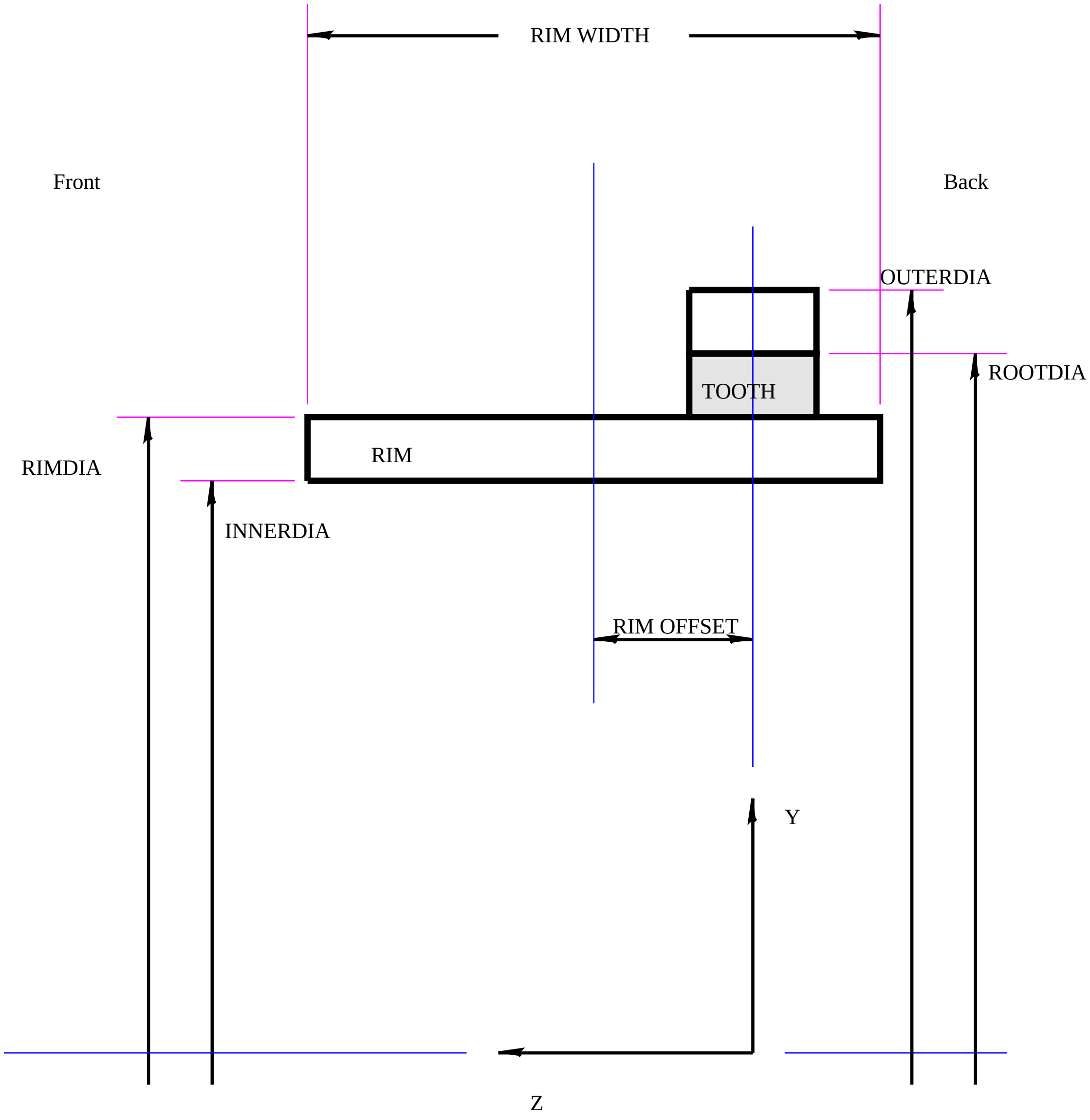

RIM WIDTH
Front
Back
OUTERDIA
ROOTDIA
TOOTH
RIMDIA
RIM
INNERDIA
RIM OFFSET
Y
Z

Figure 5.33 A Sun gear with a simple rim

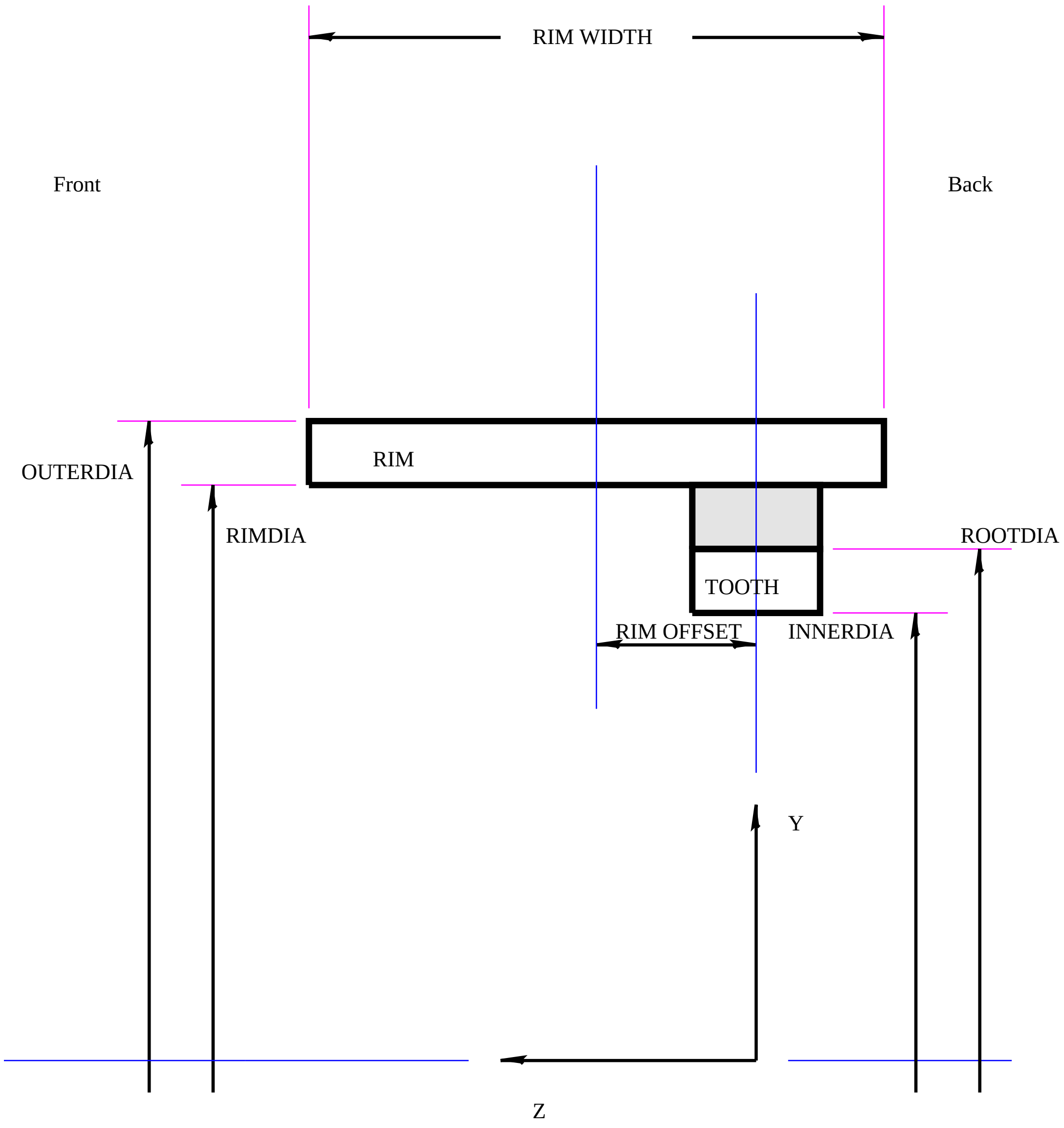
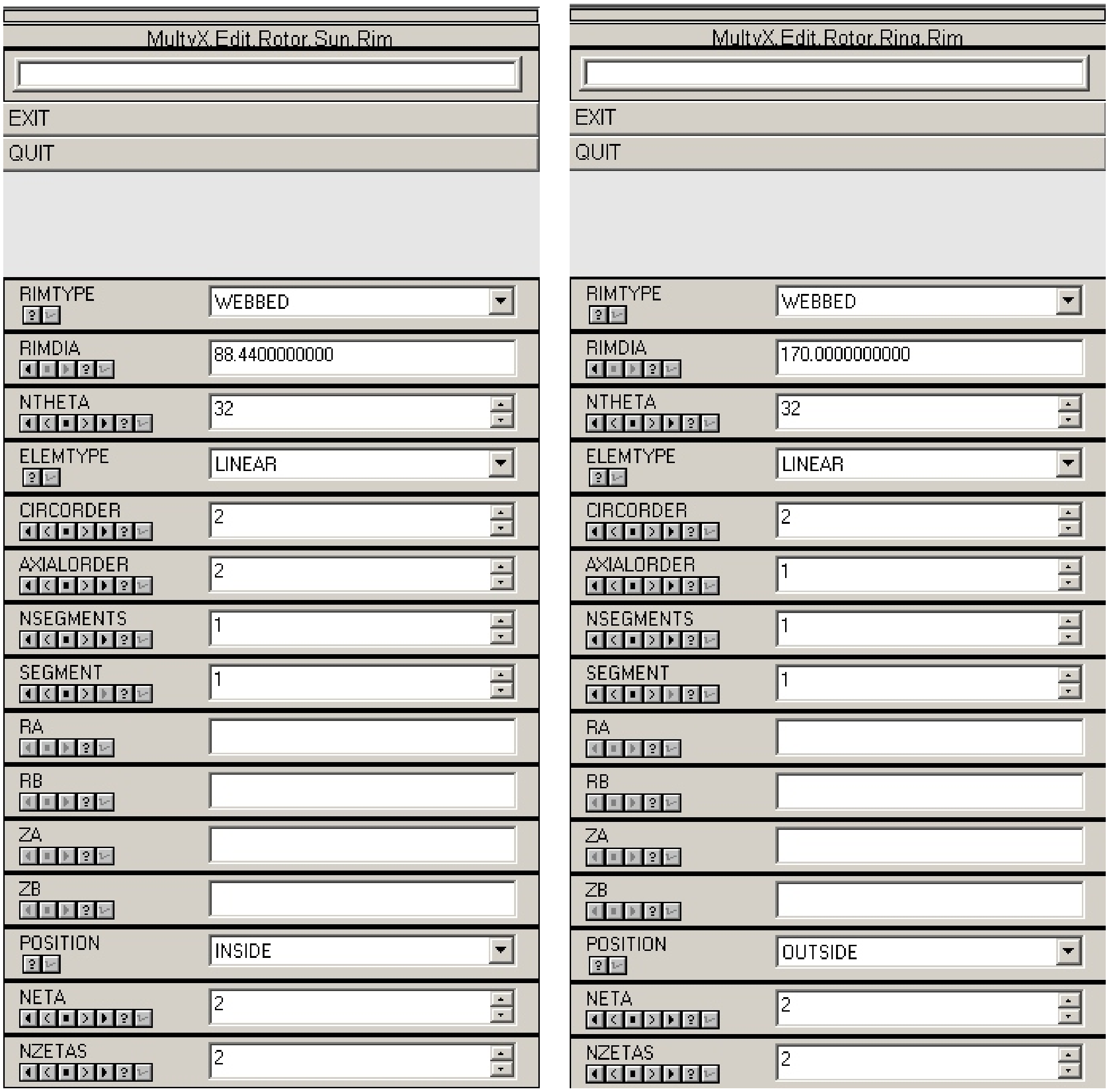

RIM WIDTH
Front
Back
RIM
OUTERDIA
RIMDIA
ROOTDIA
TOOTH
RIM OFFSET
INNERDIA
Y
Z

Figure 5.34 A ring gear with a simple rim



MultvX.Edit.Rotor.Sun.Rim

RIMTYPE	WEBBED
RIMDIA	88.4400000000
NTHETA	32
ELEMTYPE	LINEAR
CIRCORDER	2
AXIALORDER	2
NSEGMENTS	1
SEGMENT	1
RA	
RB	
ZA	
ZB	
POSITION	INSIDE
NETA	2
NZETAS	2

MultvX.Edit.Rotor.Ring.Rim

RIMTYPE	WEBBED
RIMDIA	170.0000000000
NTHETA	32
ELEMTYPE	LINEAR
CIRCORDER	2
AXIALORDER	1
NSEGMENTS	1
SEGMENT	1
RA	
RB	
ZA	
ZB	
POSITION	OUTSIDE
NETA	2
NZETAS	2

(a) Sun gear (b) Ring gear

Figure 5.35 The menu for a webbed rim

Figure 5.35 shows the menus as they appear for the WEBBED rim, for external and internal gears, respectively. Table 5.18 explains the meaning of the input parameters. The WEBBED rim is composed of an arbitrary number of ‘segments’. The position of the first segment cannot be changed. Each of the remaining segments can be placed in four different positions relative to the previous segment, as shown in Figures 5.36 through 5.43

Table 5.18 Webbed rim parameters

Item	Description
RIMDIA	Float, Rim diameter of the gear
NTHETA	Integer, Number of elements in the circular direction
ELEMTYPE	Switch, Type of finite element. Available options are LINEAR, QUADRATIC and CUBIC
CIRCORDER	Integer, Fourier series order in the circular direction
AXIALORDER	Integer, Polynomial order in the face direction
NSEGMENTS	Integer, Number of segments used to define the rim
SEGMENT	Integer, Segment number for which data is being displayed
RA	Float, Vector indexed by SEGMENT, Radial coordinate at side A.
RB	Float, Vector indexed by SEGMENT, Radial coordinate at side B.
ZA	Float, Vector indexed by SEGMENT, Z coordinate at side A.
ZB	Float, Vector indexed by SEGMENT, Z coordinate at side B.
POSITION	Switch, Vector indexed by SEGMENT, Relative position of the rim segment.
NETA	Integer, Vector indexed by SEGMENT, Number of elements in the η direction direction
NZETA	Integer, Vector indexed by SEGMENT, Number of elements in the ζ direction direction

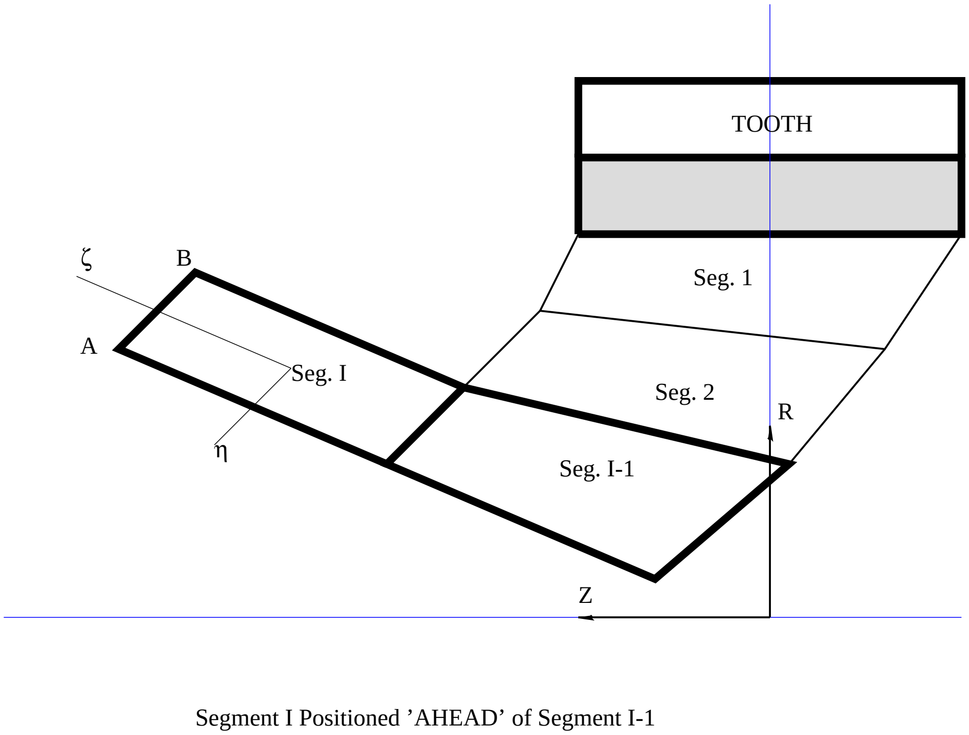

TOOTH
Seg. 1
Seg. 2
Seg. I
Seg. I-1
ζ
B
A
η
R
Z
Segment I Positioned 'AHEAD' of Segment I-1

Figure 5.36 A Sun gear with a webbed rim, showing segment i located ahead of segment $i-1$

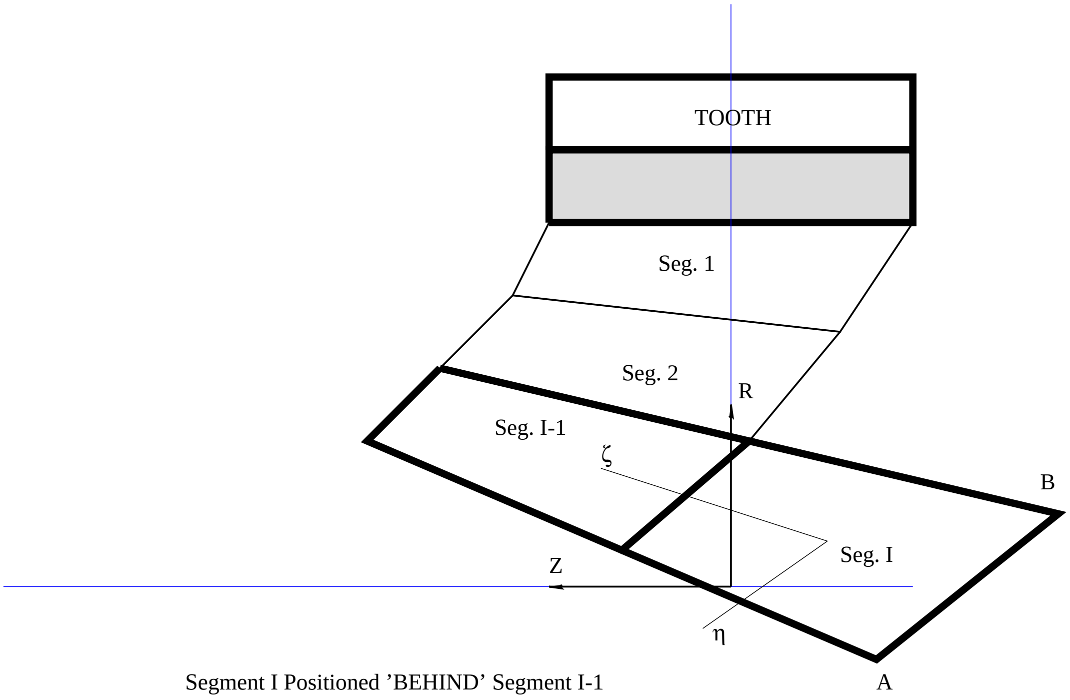
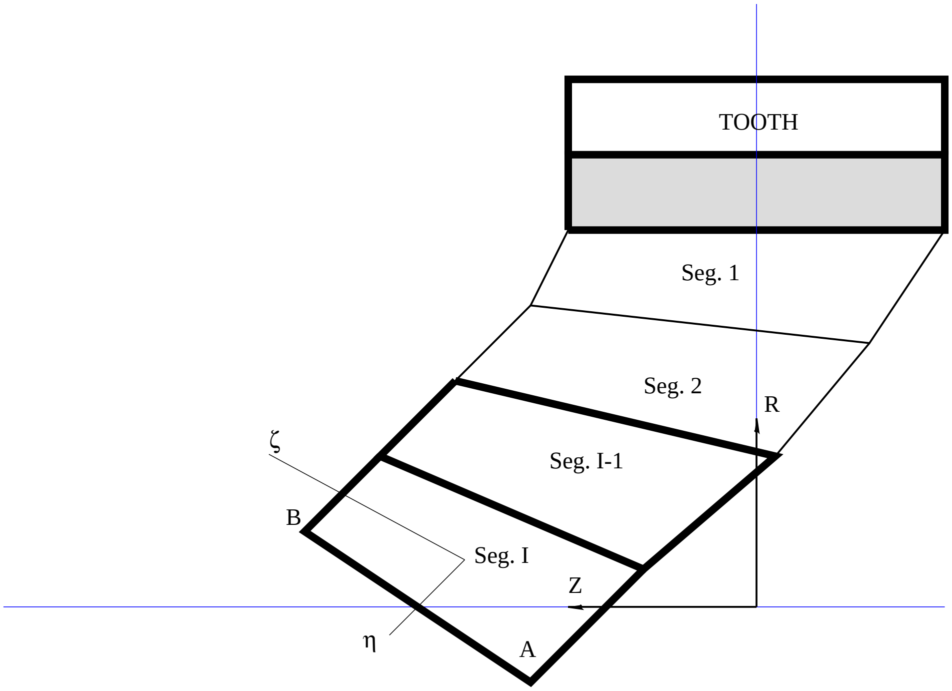
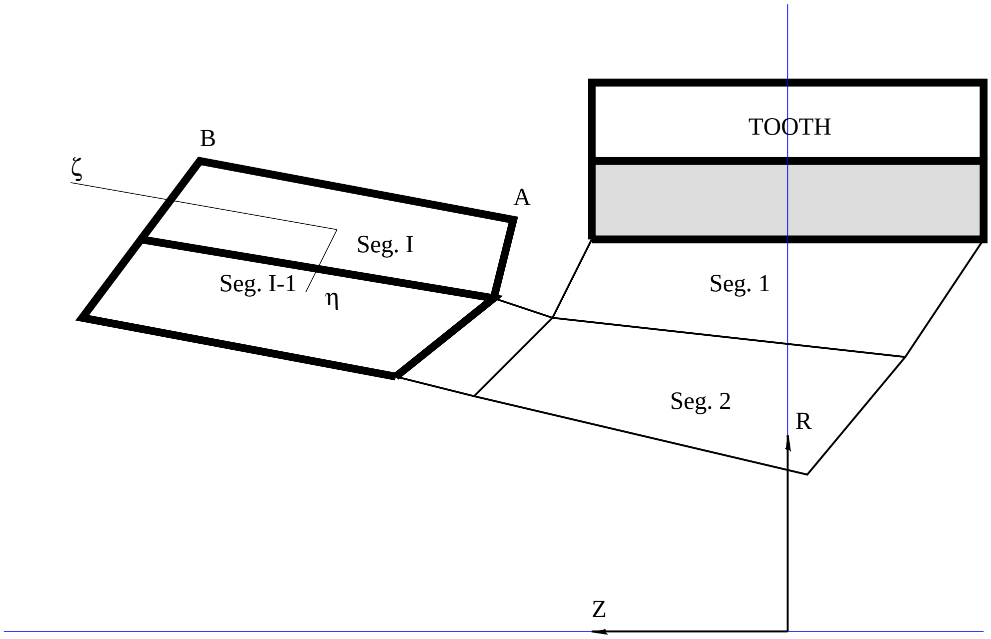

TOOTH
Seg. 1
Seg. 2
R
Seg. I-1
ζ
B
Seg. I
Z
η
A
Segment I Positioned 'BEHIND' Segment I-1

Figure 5.37 A Sun gear with a webbed rim, showing segment i located behind segment $i-1$


TOOTH
Seg. 1
Seg. 2
R
ζ
Seg. I-1
B
Seg. I
Z
η
A

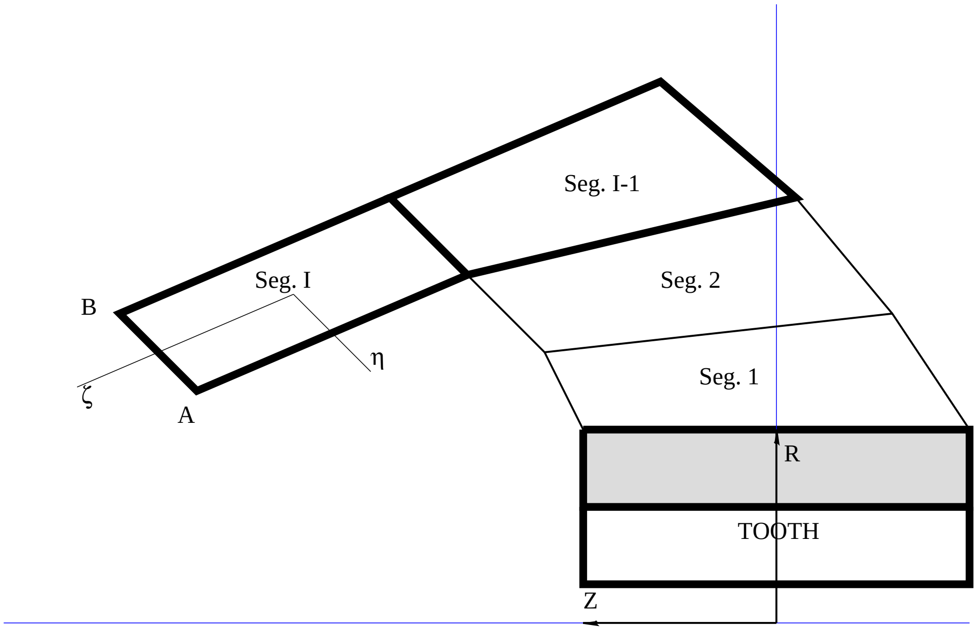
Segment I Positioned ’INSIDE’ Segment I-1

Figure 5.38 A Sun gear with a webbed rim, showing segment i located inside segment $i-1$


TOOTH
B
ζ
A
Seg. I
Seg. I-1
η
Seg. 1
Seg. 2
R
Z

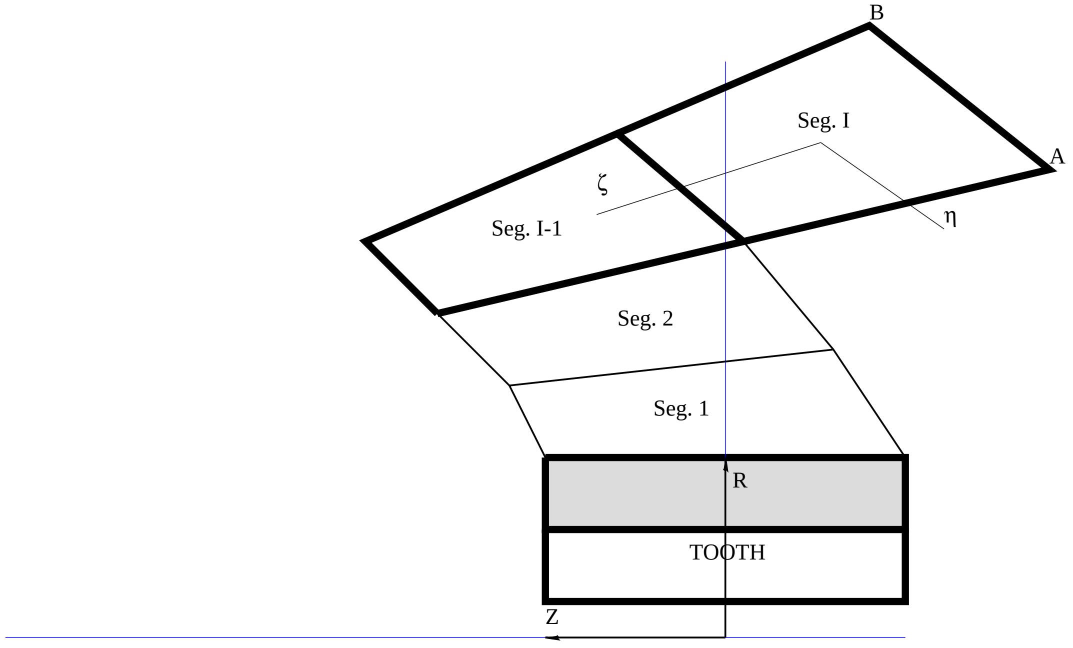
Segment I Positioned ’OUTSIDE’ Segment I-1

Figure 5.39 A Sun gear with a webbed rim, showing segment i located outside segment $i-1$


Seg. I-1
Seg. I
Seg. 2
Seg. 1
B
A
η
ζ
R
TOOTH
Z

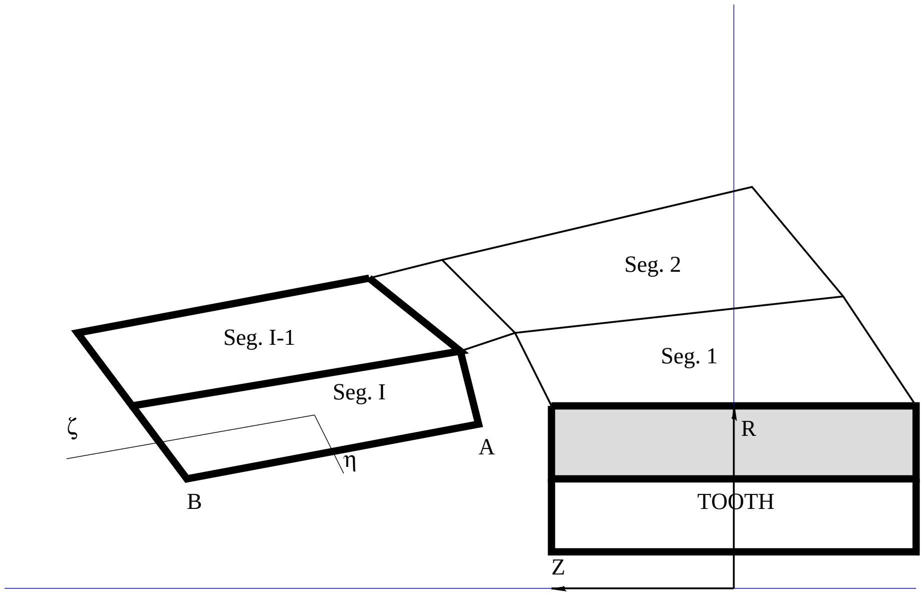
Segment I Positioned 'AHEAD' of Segment I-1

Figure 5.40 A ring gear with a webbed rim, showing segment i located ahead of segment $i-1$


B
Seg. I
A
ζ
η
Seg. I-1
Seg. 2
Seg. 1
R
TOOTH
Z

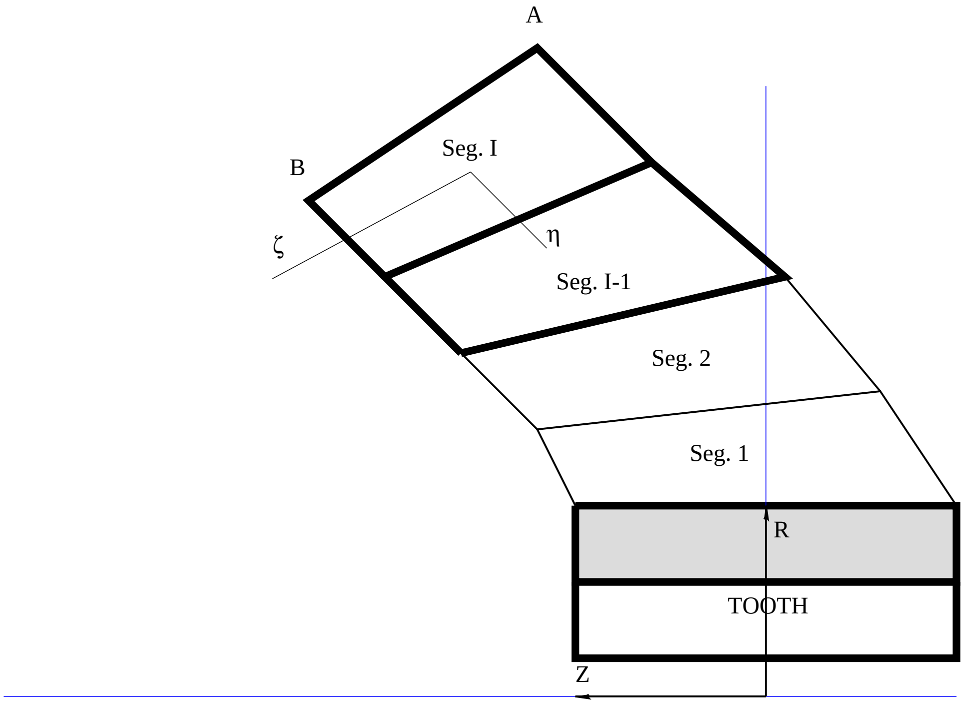
Segment I Positioned ’BEHIND’ Segment I-1

Figure 5.41 A ring gear with a webbed rim, showing segment i located behind segment $i-1$


Seg. 2
Seg. I-1
Seg. 1
Seg. I
ζ
R
A
η
B
TOOTH
Z

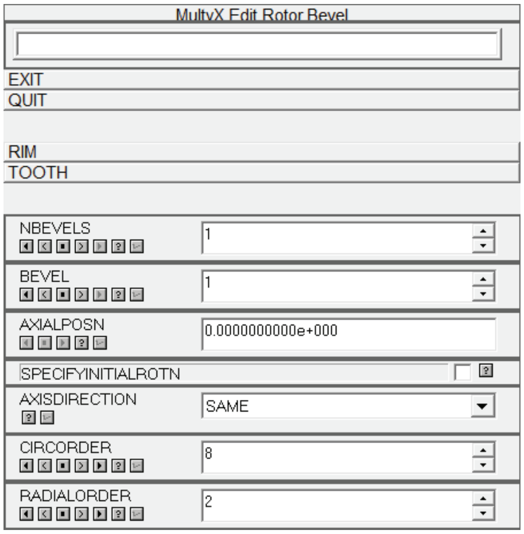
Segment I Positioned ’INSIDE’ Segment I-1

Figure 5.42 A ring gear with a webbed rim, showing segment i located inside segment $i-1$


A
B
Seg. I
ζ
η
Seg. I-1
Seg. 2
Seg. 1
R
TOOTH
Z

Segment I Positioned ’OUTSIDE’ Segment I-1

Figure 5.43 A ring gear with a webbed rim, showing segment i located outside segment $i - 1$



NBEVELS 1

BEVEL 1

AXIALPOSN 0.0000000000e+000

SPECIFYINITIALROTN ☐

AXISDIRECTION SAME

CIRCORDER 8

RADIALORDER 2

Figure 5.44 The Bevel gear menu.

5.6 Modeling Bevel gears

Transmission3D has a built-in mesh generator for any combination of two bevel tooth types and two tooth profile types. The simple tooth type models the tooth using the theoretical straight bevel form. The webbed tooth type is suitable for forged gears with major tooth truncations. The two profile types include the ‘Octoid’ and ’Point Cloud’ options. The ‘Octoid’ surface form is described by Buckingham [18]. The Point Cloud option can be used to generate a bevel tooth profile with a point cloud file consisting of the surface x, y, and z-coordinates.

Each rotor may have any number of bevel gears mounted on it. To include bevels in a rotor, check the ENABLEBEVELS flag in the ROTOR menu (Figure 5.4), and hit the BEVELS button to move to the BEVEL menu shown in Figure 5.44.

NBEVELS controls the number of bevel gears in the rotor and the BEVEL item selects the individual bevel gear for which the rest of the data is displayed. The AXIALPOSN and AXISDIRECTION items control the positioning of the bevel gear with respect to the rotor, as depicted in Figures 5.67 and 5.68.

CIRCORDER and RADIAL order control the orders of the interpolation at the gear race surface, in the circular and face width directions, respectively. The gear race is the surface at which the bevel gear can attach to other components of the rotor. All components of the rotor that attach to bevel gear must share the same value for the interpolation order.

5.6.1 The Simple Bevel Gear Tooth

The TOOTH command leads to the TOOTH menu containing the data needed to describe the tooth finite element mesh, gross tooth geometry and blank dimensions for the bevel gear tooth. The TOOTH menu for a simple type bevel tooth is shown in Figure 5.47. The inputs of this menu are described individually in Tables 5.19 and 5.20. Figure 5.48 depicts the important blank dimensions of the simple tooth geometry.

The simple bevel gear tooth menu allows the user to model a toe web by selecting the ISTOEWEB boolean box. The toe web input parameters: TOEWEBDIA, TOEWEBFILLETRAD, and TOEWEBANGLE, are also described in Tables 5.19 and 5.20. When the DOSECONDARYFACECONE boolean box is checked, the secondary face cone input fields OUTERDIAMETER and OUTERANGLE become available. The OUTERDIAMETER specifies the diameter of the outermost point of the gear, while the OUTERANGLE sets the angle between the rotational axis at the OUTERDIAMETER and the outside surface of the gear. A zero OUTERANGLE creates a cylindrical outer surface about the rotational axis. The An example 3-dimensional FE model of a simple bevel gear is shown in Figure 5.49.

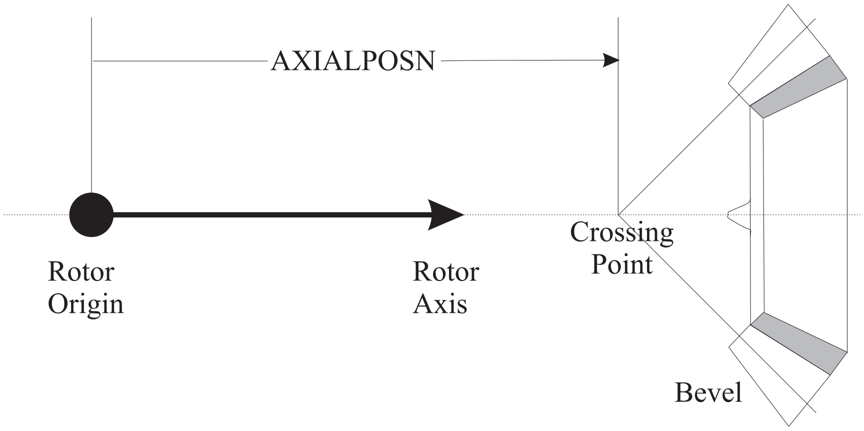

AXIALPOSN
Rotor
Origin
Rotor
Axis
Crossing
Point
Bevel

Figure 5.45 Positioning of the bevel gear with respect to the rotor when AXISDIRECTION=SAME.

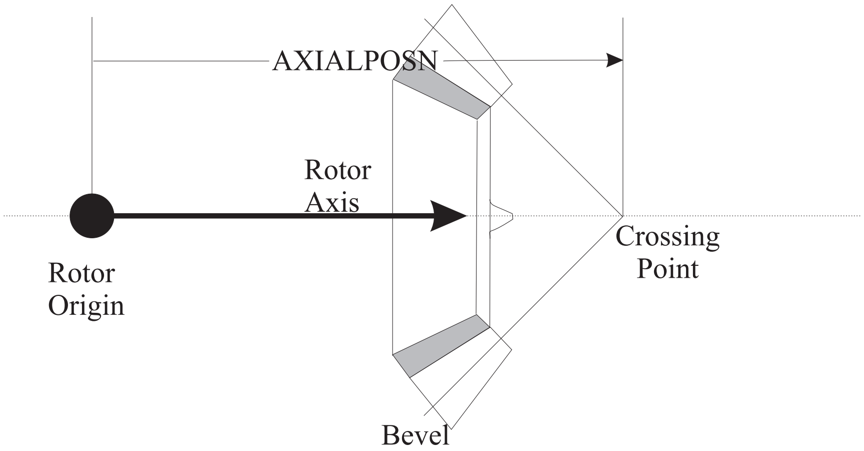
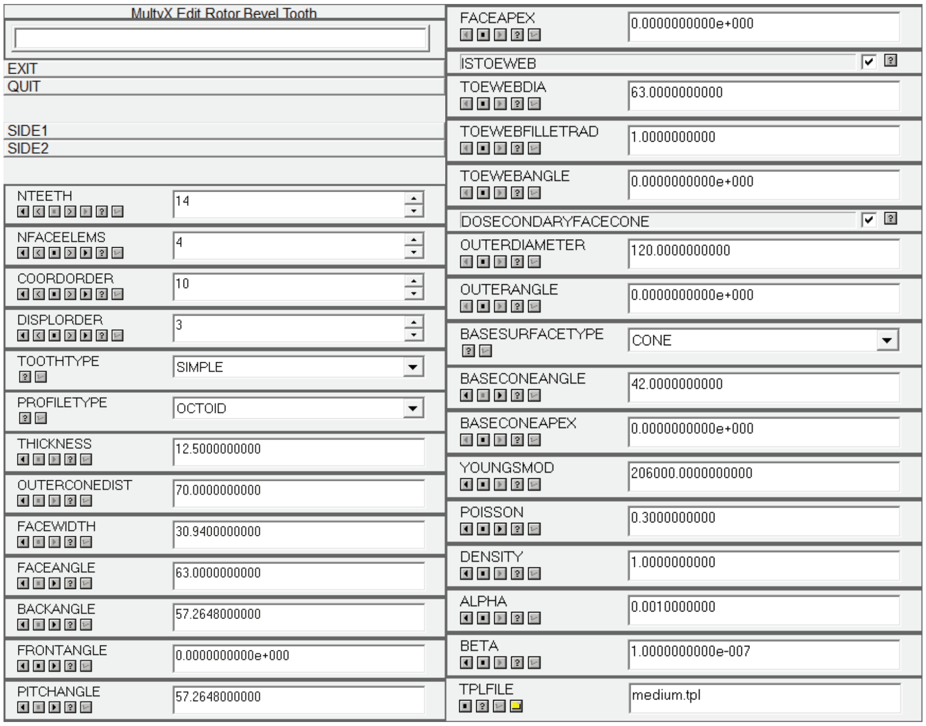

AXIALPOSN
Rotor
Axis
Rotor
Origin
Crossing
Point
Bevel

Figure 5.46 Positioning of the bevel gear with respect to the rotor when AXISDIRECTION = OPPOSITE.



NTEETH	14
NFACEELEMS	4
COORDORDER	10
DISPLORDER	3
TOOTHTYPE	SIMPLE
PROFILETYPE	OCTOID
THICKNESS	12.5000000000
OUTERCONEDIST	70.0000000000
FACEWIDTH	30.9400000000
FACEANGLE	63.0000000000
BACKANGLE	57.2648000000
FRONTANGLE	0.0000000000e+000
PITCHANGLE	57.2648000000
FACEAPEX	0.0000000000e+000
ISTOEWEB	☑
TOEWEBDIA	63.0000000000
TOEWEBFILLETRAD	1.0000000000
TOEWEBANGLE	0.0000000000e+000
DOSECONDARYFACECONE	☑
OUTERDIAMETER	120.0000000000
OUTERANGLE	0.0000000000e+000
BASESURFACETYPE	CONE
BASECONEANGLE	42.0000000000
BASECONEAPEX	0.0000000000e+000
YOUNGSMOD	206000.0000000000
POISSON	0.3000000000
DENSITY	1.0000000000
ALPHA	0.0010000000
BETA	1.0000000000e-007
TPLFILE	medium.tpl

Figure 5.47 The Simple Bevel gear tooth menu.

If the BASESURFACETYPE switch is set to CONE, then the bevel gear race is conical, and the two parameters BASECONEANGLE and BASECONEAPEX are used to specify this cone. If BASESURFACETYPE is set to CYLINDER, then the value of BASECYLINDERDIAMETER has to be specified. The cylindrical base surface is useful when connecting the bevel gear to a race of a shaft segment. The conical race is useful for connecting the bevel gear to a carrier structure.

The SIDE1 and SIDE2 commands in the TOOTH menu (Figure 5.47) lead to menu like the one shown in Figure 5.50. This allows us to specify different values for the BLADEANGLE and EDGERADIUS (Figure 5.51) for the two sides of the bevel gear tooth. Each side can also have a different ROOTANGLE (Figure 5.48). The two sides of the bevel gear tooth are numbered as shown in Figure 5.52.

Table 5.19 Simple bevel design and blank parameters

Item	Description
NTEETH	Integer, Number of teeth on the pinion/gear
NFACEELEMS	Integer, Number of elements across the face width of the pinion/gear
COORDORDER	Integer, Limit on the order of coordinate axodes for the pinion/gear
DISPLORDER	Integer, Limit on displ order of axodes
TOOTHTYPE	Switch, Controls the type of tooth used for the bevel tooth
PROFILETYPE	Switch, Controls the type of profile used to generate the bevel tooth
THICKNESS	Float, Mean transverse tooth thickness
OUTERCONEDIST	Float, Distance from the apex of the pitch cone to the outer ends of the tooth
FACEWIDTH	Float, Face width of the tooth
FACEANGLE	Float, Angle between the element of the face cone and axis(Deg)
BACKANGLE	Float, Angle between the element of the back cone and the plane perpendicular to the axis of rotation(Deg)
FRONTANGLE	Float,Angle between the element of the front cone and the plane perpendicular to the axis of rotation(Deg)
PITCHANGLE	Float, Angle between the element of the pitch cone and axis(Deg)
FACEAPEX	Float, Face apex beyond crossing point distance
ISTOEWEB	Boolean, Enables the toe web feature
TOEWEBDIA	Float, Diameter of the toe web

Table 5.20 Simple bevel design and blank parameters (Continued)

Item	Description
TOEWEBFILLETRAD	Float, Magnitude of fillet radius of surface between toe web, tooth profile, and tooth root surfaces
TOEWEBANGLE	Float, Angle between toe web and rotational axis at the toe web diameter (zero angle = cylindrical web)
DOSECONDARYFACECONE	Boolean, Truncates the outermost portion of the tooth with the secondary face cone
OUTERDIAMETER	Float, Diameter of secondary face cone
OUTERANGLE	Float, Angle between outer tooth surface and rotational axis at the outer diameter of the face cone
BASESURFACEETYPE	Switch, Kind of surface to be used as the base surface(CYLINDER/CONE)
BASECYLINDERDIAMETER	Float, Diameter of the cylinder used as the base of the tooth mesh(IF BASESURFACETYPE=CYLINDER)
BASECONEANGLE	Float, Angle(Deg) between the element of the base cone and the axis(IF BASESURFACETYPE=CONE)
BASECONEAPEX	Float, Inner cone apex beyond crossing point distance(IF BASESURFACETYPE=CONE)
YOUNGSMOD	Float, Youngs modulus for the pinion/gear
POISSON	Float, Poisson’s ratio for the pinion/gear
DENSITY	Float, Density of the pinion/gear
ALPHA	Float, Damping constant alpha for the pinion/gear
BETA	Float, Damping constant beta for the pinion/gear
TPLFILE	Switch, Template file for the pinion/gear(Refer to appendix for details)

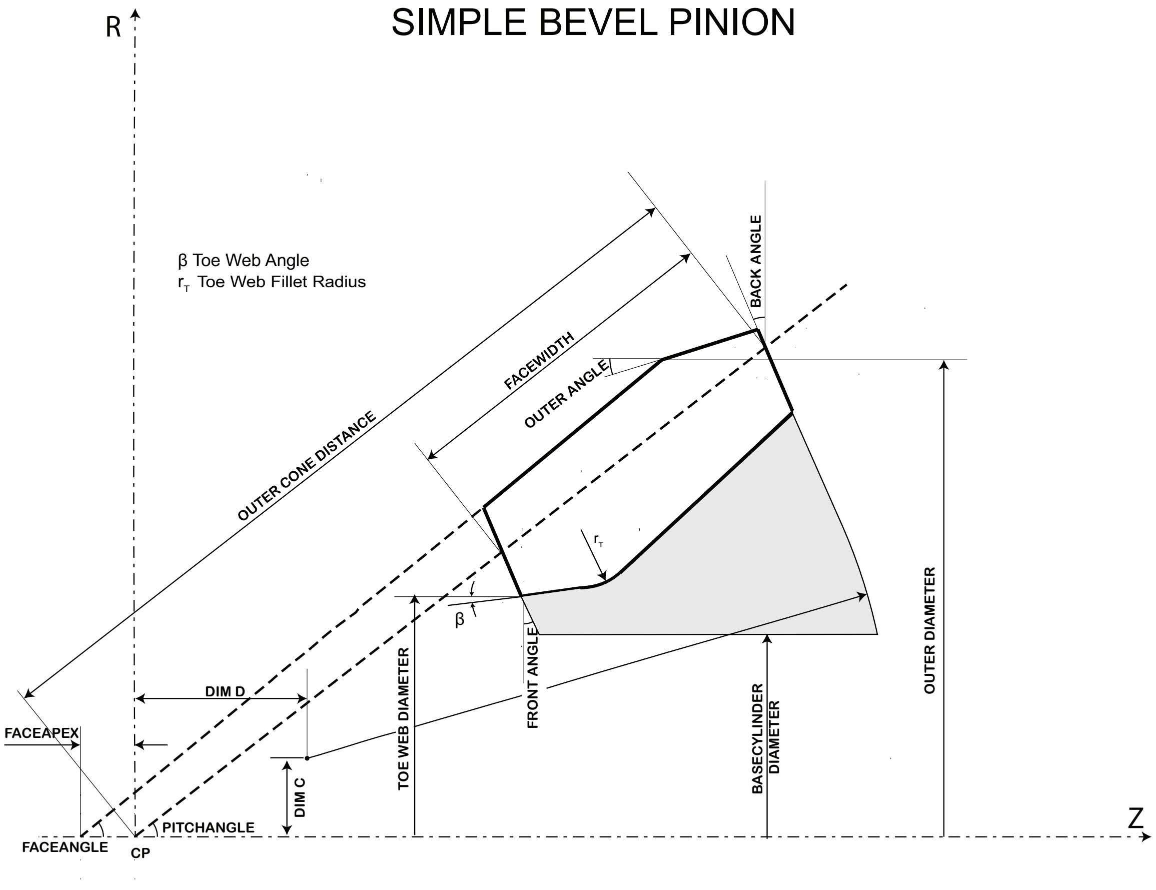

SIMPLE BEVEL PINION
R
β Toe Web Angle
r_T Toe Web Fillet Radius
BACK ANGLE
FACEWIDTH
OUTER ANGLE
OUTER CONE DISTANCE
r_T
β
OUTER DIAMETER
TOE WEB DIAMETER
FRONT ANGLE
BASECYLINDER DIAMETER
DIM D
FACEAPEX
DIM C
PITCHANGLE
FACEANGLE
CP
Z

Figure 5.48 The Simple Bevel gear blank dimensions.

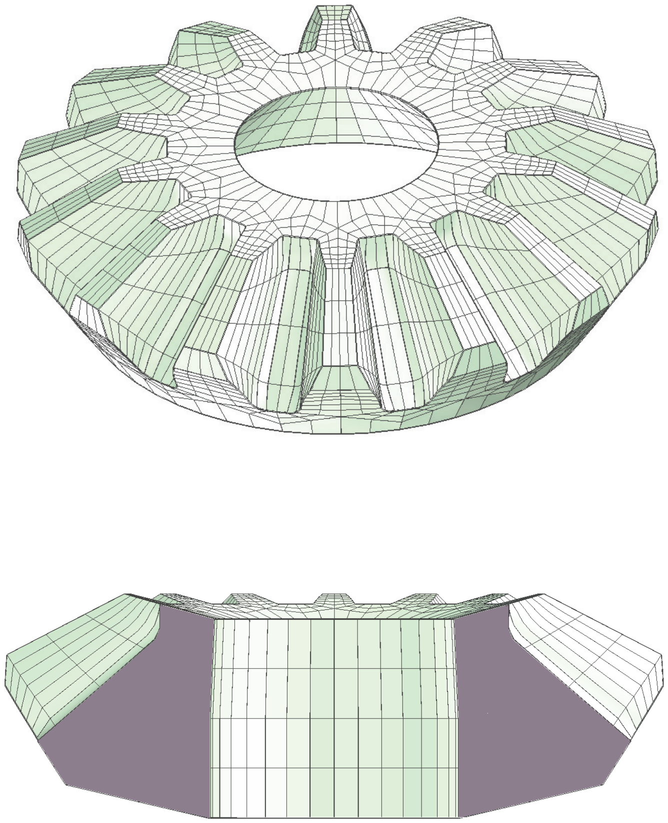
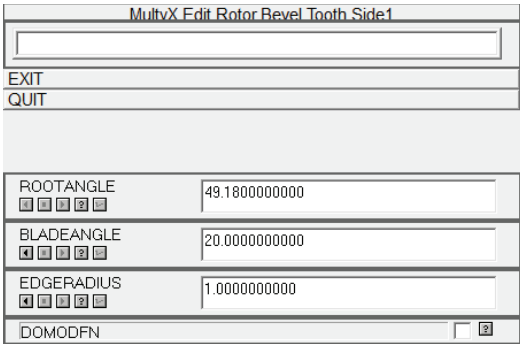


Figure 5.49 The simple bevel gear FE model.


MultyX Edit Rotor Bevel Tooth Side1
EXIT
QUIT

ROOTANGLE 49.1800000000

BLADEANGLE 20.0000000000

EDGERADIUS 1.0000000000

DOMODFN ☐

Figure 5.50 The Bevel gear tooth side menus.

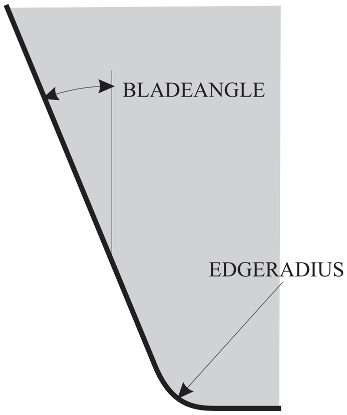

BLADEANGLE
EDGERADIUS

Figure 5.51 The Bevel gear cutter blade dimensions.

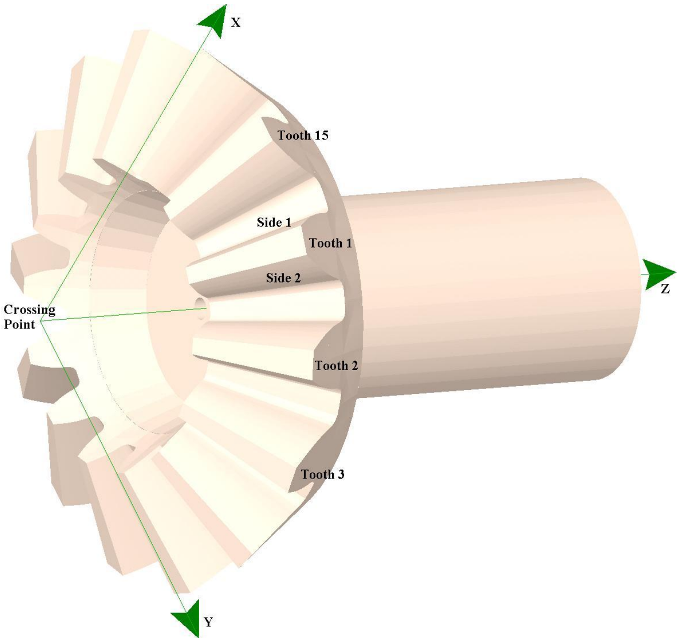
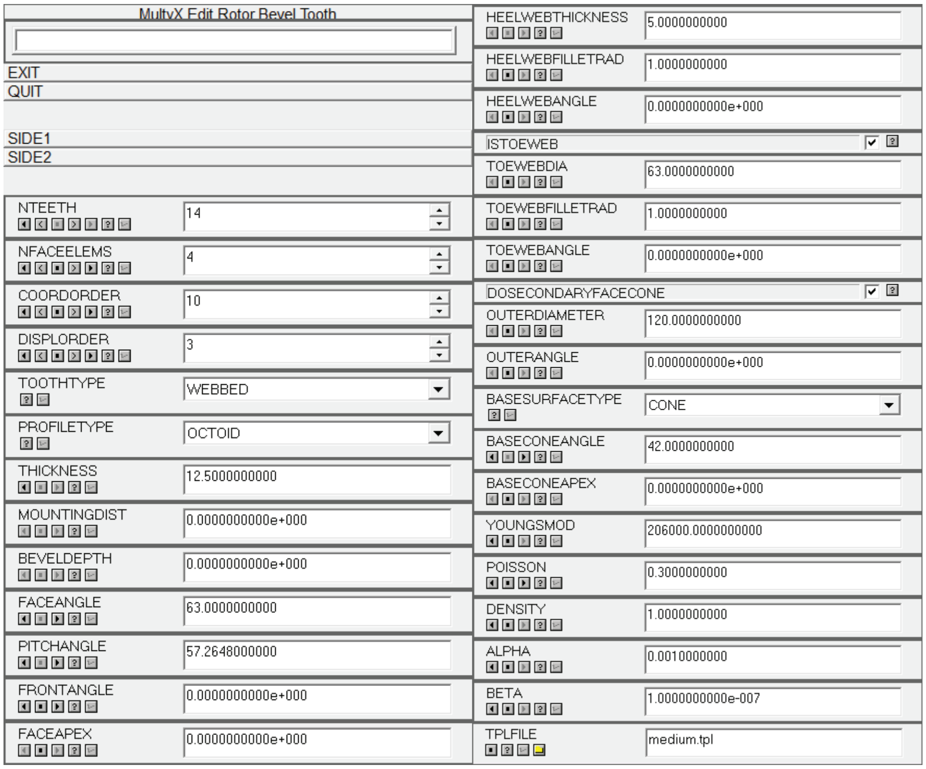

X
Tooth 15
Side 1
Tooth 1
Side 2
Z
Crossing
Point
Tooth 2
Tooth 3
Y

Figure 5.52 The Bevel gear tooth and side numbering conventions



MultyX Edit Rotor Bevel Tooth

EXIT
QUIT

SIDE1
SIDE2

NTEETH 14
NFACEELEMS 4
COORDORDER 10
DISPLORDER 3
TOOTHTYPE WEBBED
PROFILETYPE OCTOID
THICKNESS 12.5000000000
MOUNTINGDIST 0.0000000000e+000
BEVELDEPTH 0.0000000000e+000
FACEANGLE 63.0000000000
PITCHANGLE 57.2648000000
FRONTANGLE 0.0000000000e+000
FACEAPEX 0.0000000000e+000
HEELWEBTHICKNESS 5.0000000000
HEELWEBFILLETRAD 1.0000000000
HEELWEBANGLE 0.0000000000e+000
ISTOEWEB ☑
TOEWEBDIA 63.0000000000
TOEWEBFILLETRAD 1.0000000000
TOEWEBANGLE 0.0000000000e+000
DOSECONDARYFACECONE ☑
OUTERDIAMETER 120.0000000000
OUTERANGLE 0.0000000000e+000
BASESURFACETYPE CONE
BASECONEANGLE 42.0000000000
BASECONEAPEX 0.0000000000e+000
YOUNGSMOD 206000.0000000000
POISSON 0.3000000000
DENSITY 1.0000000000
ALPHA 0.0010000000
BETA 1.0000000000e-007
TPLFILE medium.tpl

Figure 5.53 The Webbed Bevel gear tooth menu.

5.6.2 The Webbed Bevel Gear Tooth

Figure 5.53 shows the bevel TOOTH input menu for a bevel gear with TOOTHTYPE = WEBBED. This menu contains data needed to describe the tooth finite element mesh, gross tooth geometry and blank dimensions for a webbed tooth bevel gear. The webbed tooth type is suitable for forged gears with major tooth truncations and allows for specification of the MOUNATINGDIST and BEVELDEPTH parameters, rather than the OUTERCONEDIST and FACEWIDTH parameters specified for the SIMPLE bevel gear. In addition to the toe web feature described for the simple bevel gear, the webbed tooth type includes the heel web feature. The blank dimensions for the webbed gear tooth are pictured in Figure 5.54. Tables 5.21 and 5.22 describe the tooth menu inputs for the webbed type bevel gear and an example of a 3-dimensional webbed bevel gear is shown in Figure 5.55.

The webbed bevel gear rim must join to the base surface of the gear. Doing so requires 2 shafts, one with two segments and one with a single segment. The two-segment shaft must contain one cylindrical segment and one conical segment two join to the cylindrical and conical base surface segments, respectively. The second shaft is required to join to the outer surface of the gear. The shaft menu's ENABLEFRONTINTERFACE or ENABLEBACKINTERFACE feature must be used to do so. The information window outputs the R and Z values shown in Figure 5.56 in order to determine the required shaft segment parameters.

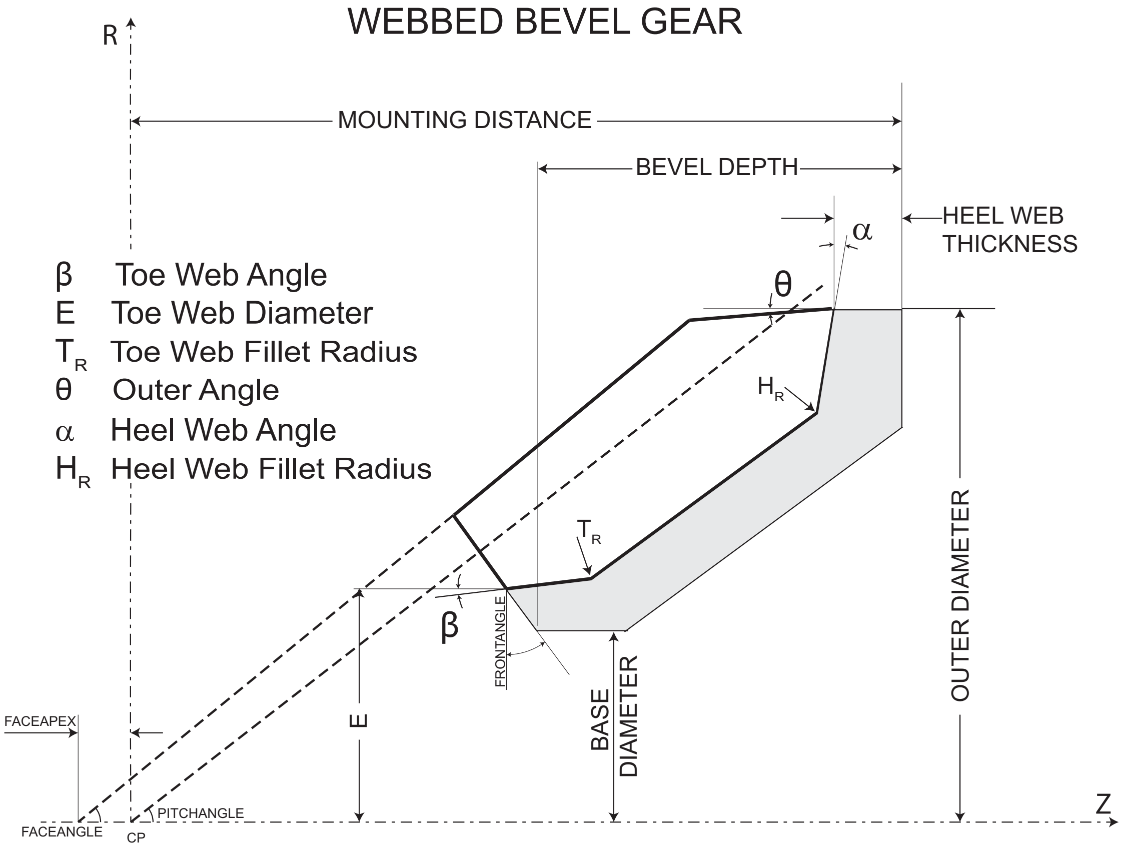

WEBBED BEVEL GEAR
R
MOUNTING DISTANCE
BEVEL DEPTH
HEEL WEB THICKNESS
α
θ
β Toe Web Angle
E Toe Web Diameter
T_R Toe Web Fillet Radius
θ Outer Angle
α Heel Web Angle
H_R Heel Web Fillet Radius
H_R
T_R
β
FRONTANGLE
E
BASE DIAMETER
OUTER DIAMETER
FACEAPEX
FACEANGLE
CP
PITCHANGLE
Z

Figure 5.54 The Webbed Bevel gear blank dimensions.

Table 5.21 Webbed bevel design and blank parameters

Item	Description
NTEETH	Integer, Number of teeth on the pinion/gear
NFACEELEMS	Integer, Number of elements across the face width of the pinion/gear
COORDORDER	Integer, Limit on the order of coordinate axodes for the pinion/gear
DISPLORDER	Integer, Limit on displ order of axodes
TOOTHTYPE	Switch, Controls the type of tooth used for the bevel tooth
PROFILETYPE	Switch, Controls the type of profile used to generate the bevel tooth
THICKNESS	Float, Mean transverse tooth thickness
MOUNTINGDIST	Float, Axial distance of the back face of the gear from the crossing point
BEVELDEPTH	Float, Axial distance from mounting distance measuring point on the back face (heel) to front face (toe) of the bevel gear
FACEANGLE	Float, Angle between the element of the face cone and axis(Deg)
BACKANGLE	Float, Angle between the element of the back cone and the plane perpendicular to the axis of rotation(Deg)
FRONTANGLE	Float,Angle between the element of the front cone and the plane perpendicular to the axis of rotation(Deg)
PITCHANGLE	Float, Angle between the element of the pitch cone and axis(Deg)
FACEAPEX	Float, Face apex beyond crossing point distance
HEELWEBTHICKNESS	Float, Thickness of the heel web measured in the axial direction from the mounting distance measuring surface
HEELWEBFILLETRAD	Float, Fillet radius of the surface at the tooth profile, tooth root, and heel web intersecting surfaces

Table 5.22 Webbed bevel design and blank parameters (Continued)

Item	Description
HEELWEBANGLE	Float, Angle between the heel web surface and the radial axis (zero angle = cylindrical about radial axis)
ISTOEWEB	Boolean, Enables the toe web feature
TOEWEBDIA	Float, Diameter of the toe web
TOEWEBFILLETRAD	Float, Magnitude of fillet radius of surface between toe web, tooth profile, and tooth root surfaces
TOEWEBANGLE	Float, Angle between toe web and rotational axis at the toe web diameter (zero angle = cylindrical web)
DOSECONDARYFACECONE	Boolean, Truncates the outermost portion of the tooth with the secondary face cone
OUTERDIAMETER	Float, Diameter of secondary face cone
OUTERANGLE	Float, Angle between outer tooth surface and rotational axis at the outer diameter of the face cone
BASESURFACEETYPE	Switch, Kind of surface to be used as the base surface(CYLINDER/CONE)
BASECYLINDERDIAMETER	Float, Diameter of the cylinder used as the base of the tooth mesh(IF BASESURFACETYPE=CYLINDER)
BASECONEANGLE	Float, Angle(Deg) between the element of the base cone and the axis(IF BASESURFACETYPE=CONE)
BASECONEAPEX	Float, Inner cone apex beyond crossing point distance(IF BASESURFACETYPE=CONE)
YOUNGSMOD	Float, Youngs modulus for the pinion/gear
POISSON	Float, Poisson's ratio for the pinion/gear
DENSITY	Float, Density of the pinion/gear
ALPHA	Float, Damping constant alpha for the pinion/gear
BETA	Float, Damping constant beta for the pinion/gear
TPLFILE	Switch, Template file for the pinion/gear(Refer to appendix for details)

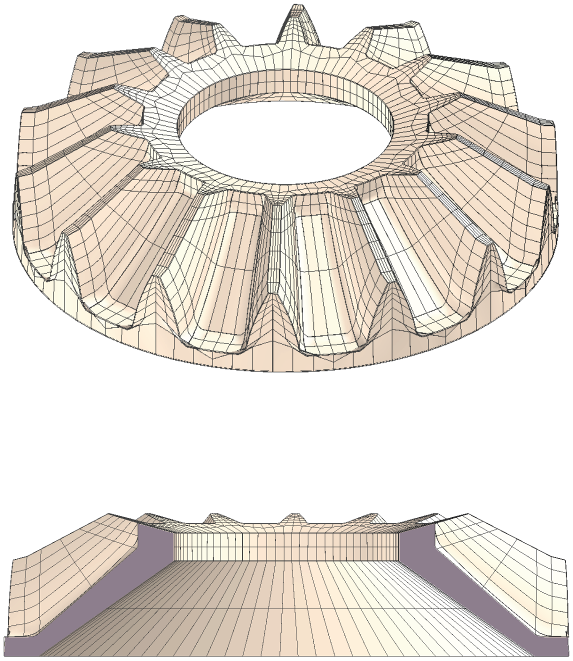


Figure 5.55 The Webbed Bevel gear FE model.

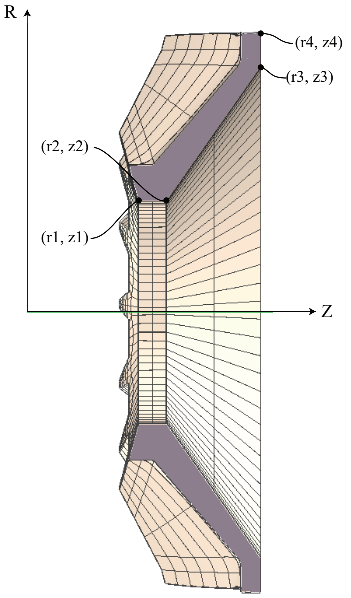
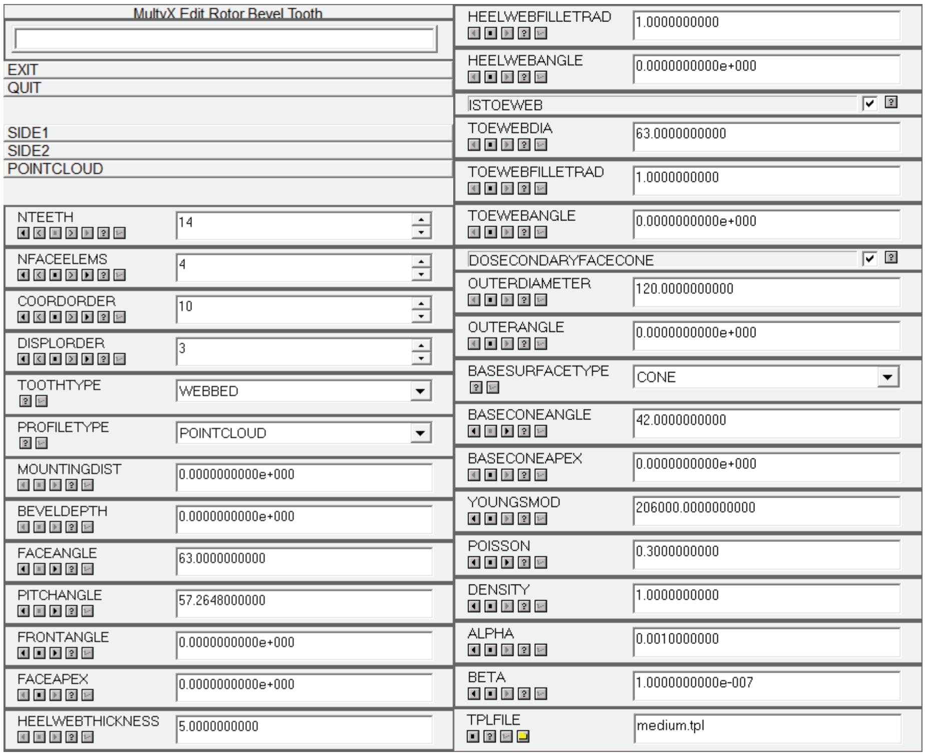

R
(r4, z4)
(r3, z3)
(r2, z2)
(r1, z1)
Z

Figure 5.56 The webbed bevel gear rim parameters.



NTEETH	14
NFACEELEMS	4
COORDORDER	10
DISPLORDER	3
TOOTHTYPE	WEBBED
PROFILETYPE	POINTCLOUD
MOUNTINGDIST	0.0000000000e+000
BEVELDEPTH	0.0000000000e+000
FACEANGLE	63.0000000000
PITCHANGLE	57.2648000000
FRONTANGLE	0.0000000000e+000
FACEAPEX	0.0000000000e+000
HEELWEBTHICKNESS	5.0000000000
HEELWEBFILLETRAD	1.0000000000
HEELWEBANGLE	0.0000000000e+000
ISTOEWEB	☑
TOEWEBDIA	63.0000000000
TOEWEBFILLETRAD	1.0000000000
TOEWEBANGLE	0.0000000000e+000
DOSECONDARYFACECONE	☑
OUTERDIAMETER	120.0000000000
OUTERANGLE	0.0000000000e+000
BASESURFACETYPE	CONE
BASECONEANGLE	42.0000000000
BASECONEAPEX	0.0000000000e+000
YOUNGSMOD	206000.0000000000
POISSON	0.3000000000
DENSITY	1.0000000000
ALPHA	0.0010000000
BETA	1.0000000000e-007
TPLFILE	medium.tpl

Figure 5.57 The tooth menu with the point cloud profile type.

5.6.3 The Point Cloud Bevel Gear Tooth Profile

The alternative to using the ’Octoid’ tooth profile geometry is defining an arbitrary tooth profile with a user defined ’Point Cloud’ file. The TOOTH menu with the POINTCLOUD PROFILETYPE selected is shown in Figure 5.57. Selecting the point cloud tooth profile option does not change the remaining inputs of the tooth menu.

Figure 5.58 shows a bevel gear with a tooth slot surface shaded in red. The point cloud file contains a matrix with the positions of each of the tooth slot surface points. The matrix size is entered into the POINTCLOUD menu (Figure 5.59) fields NCOLS and NROWS. NCOLS and NROWS represent the number of points in the tooth slot profile and facewidth directions, respectively. The surface point x, y, and z-coordinates are entered into the DATA menu (Figure 5.59) from the point cloud file. These coordinates are expressed in the bevel gear reference frame oriented as shown in Figure 5.58 with its origin coincident with the crossing point crossing point.

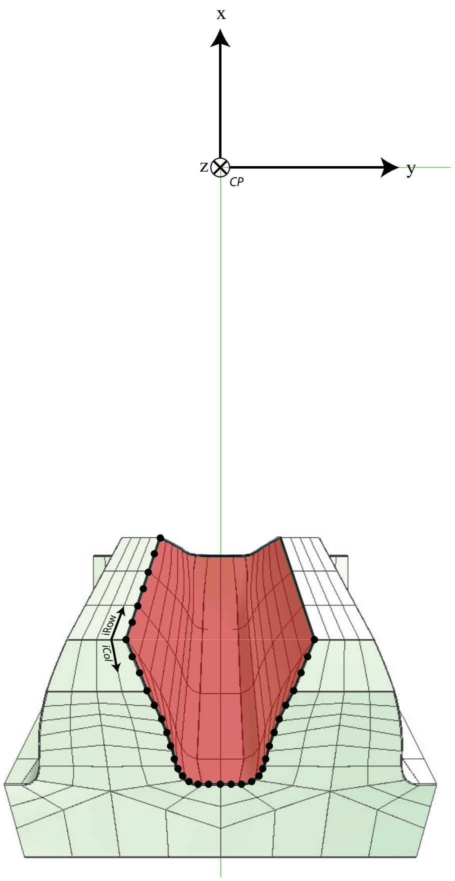
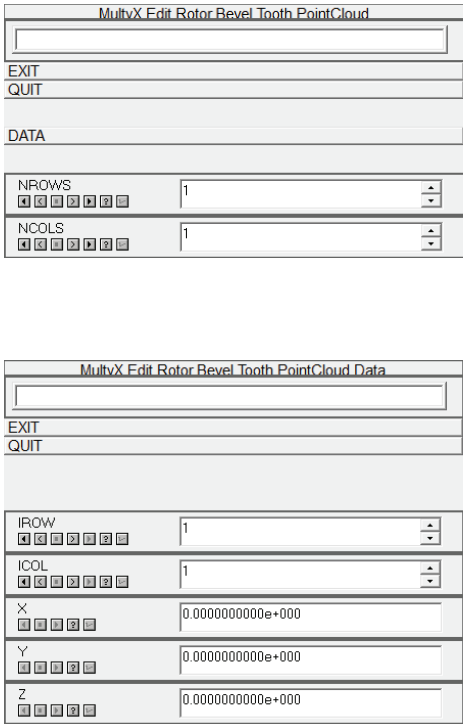

x
z
y
CP
iRow
iCol

Figure 5.58 The bevel tooth slot.


MultyX Edit Rotor Bevel Tooth PointCloud
EXIT
QUIT
DATA
MultyX Edit Rotor Bevel Tooth PointCloud Data
EXIT
QUIT

NROWS 1

NCOLS 1

IROW 1

ICOL 1

X 0.0000000000e+000

Y 0.0000000000e+000

Z 0.0000000000e+000

Figure 5.59 The Point Cloud menus.

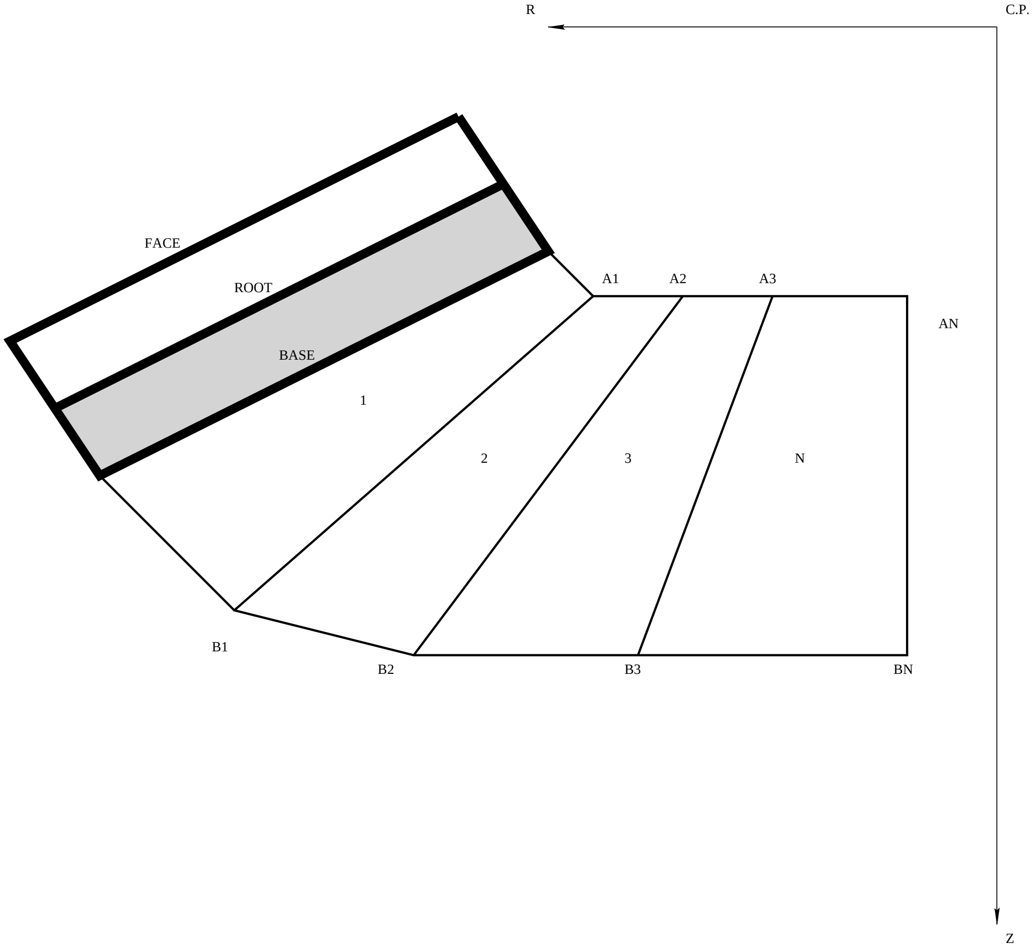
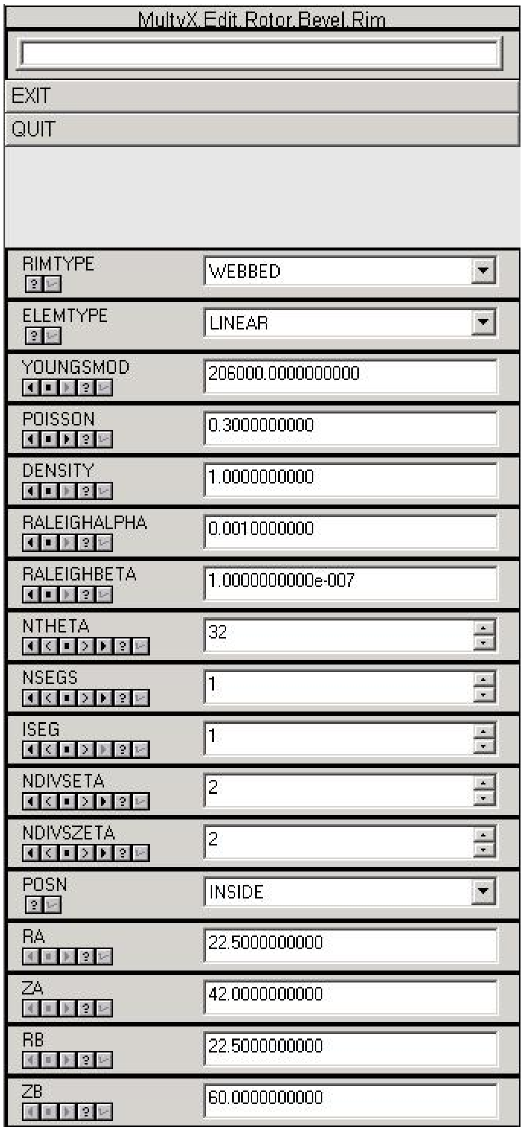


Figure 5.60 The Bevel gear rim dimensions.

5.6.4 The Bevel gear rim

The RIM command in Figure 5.44 leads us to the Rim data menu for the bevel as shown in Figure 5.61. The RIMTYPE item can be either NONE or WEBBED. If it is set to NONE, then the base of the tooth finite element model will be constrained as the race surface.

The WEBBED rim is specified by sequence of segments as shown in Figure 5.60. The first segment is closest to the tooth, and the last segment is the farthest. Each segment ‘i’ has two endpoints. Depending on the POSITION of the rim segment, there are four different ways in which it attaches to the previous segemt (Figures 5.36 to 5.39) Table 5.23 shows the meaning of the parameters in this menu.



RIMTYPE	WEBBED
ELEMTYPE	LINEAR
YOUNGSMOD	206000.0000000000
POISSON	0.3000000000
DENSITY	1.0000000000
RALEIGHALPHA	0.0010000000
RALEIGHBETA	1.0000000000e-007
NTHETA	32
NSEGS	1
ISEG	1
NDIVSETA	2
NDIVSZETA	2
POSN	INSIDE
RA	22.5000000000
ZA	42.0000000000
RB	22.5000000000
ZB	60.0000000000

Figure 5.61 The Bevel gear rim menu.

Table 5.23 The bevel gear rim parameters

Item	Description
RIMTYPE	Switch, Options are NONE and WEBBED
ELEMTYPE	Switch, Type of finite element. Available options are LINEAR, QUADRATIC and CUBIC
YOUNGSMOD	Float, Youngs modulus for the bevel gear
POISSON	Float, Poisson’s ratio for the bevel gear
DENSITY	Float, Density of the bevel gear
RALEIGHALPHA	Float, Damping constant alpha for the bevel gear
RALEIGHBETA	Float, Damping constant beta for the bevel gear
NTHETA	Integer, The is the number of finite elements used in the circular direction of the rim
NSEGS	Integer, Number of segments used to define the rim
ISEG	Integer, Segment number for which data is being displayed
NDIVSETA	Integer, Vector indexed by ISEG, Number of elements along the η direction of the segment.
NDIVSZETA	Integer, Vector indexed by ISEG, Number of elements along the ζ direction of the segment.
POSITION	Switch, Vector indexed by SEGMENT, Relative position of the rim segment.
RA	Float, Vector indexed by ISEG, Radial coordinate at side A.
ZA	Float, Vector indexed by ISEG, Z coordinate at side A.
RB	Float, Vector indexed by ISEG, Radial coordinate at side B.
ZB	Float, Vector indexed by ISEG, Z coordinate at side B.

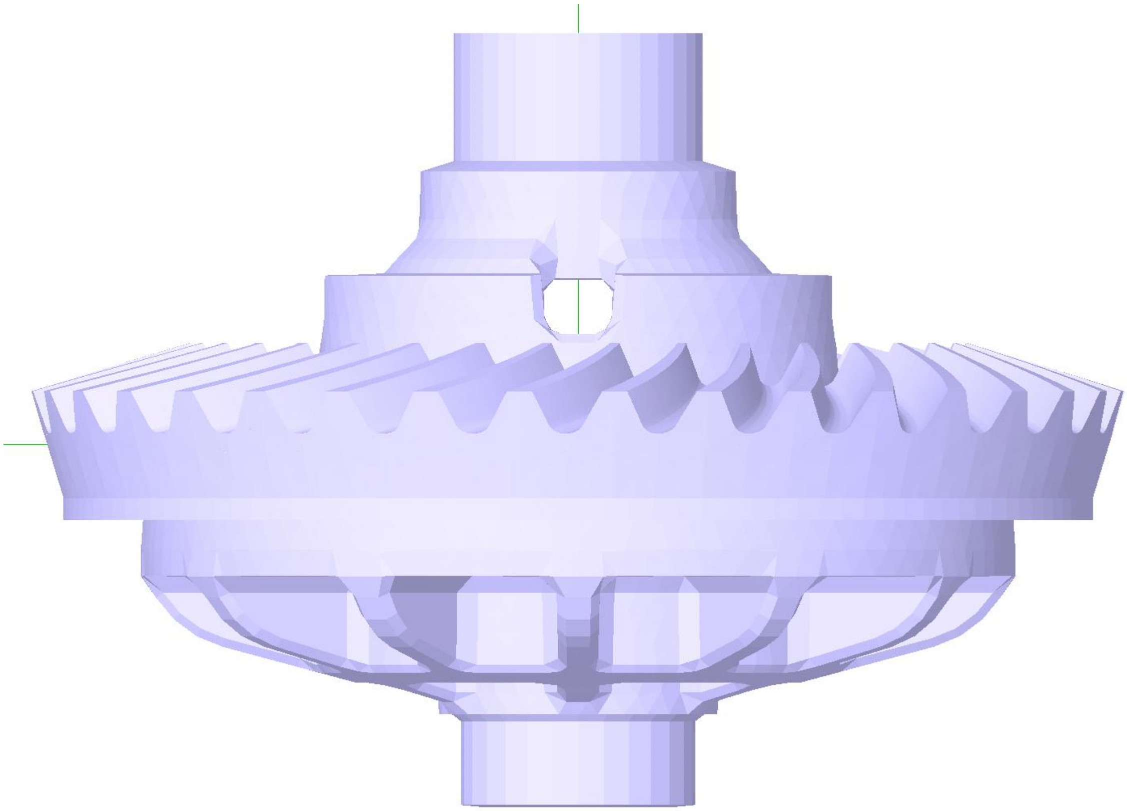


Figure 5.62 A rotor with an attached hypoid gear.

5.7 Modeling Hypoid Gears

Transmission3D can include models of Hypoid gears by selecting the ENABLEHYPOIDS option within the ROTOR menu. Figure 5.62 shows a rotor with an attached hypoid gear model. This hypoid model, shown by itself in Figure 5.63, consists of two parts, a gear tooth model (Figure 5.64) and a rim mesh (Figure 5.65). The HYPOID menu (Figure 5.66) is used to model the hypoid gear tooth and rim.

NHYPOIDS is the number of hypoid gears on the rotor. The HYPOID item selects the individual hypoid gear for which the remaining data is displayed. AXIALPOSN and AXISDIRECTION position the hypoid gear with respect to the rotor origin and axis, as shown in figures 5.67 and 5.68.

A typical hypoid gear tooth can be modeled using one of the two following methods:(1) By modeling the gears directly within the *Guide* menus similar to those found within the *HypoidFaceMilled* or *HypoidFaceHobbed* packages, or (2) By importing a mesh file generated by the *HypoidFaceMilled* or *HypoidFaceHobbed* packages.

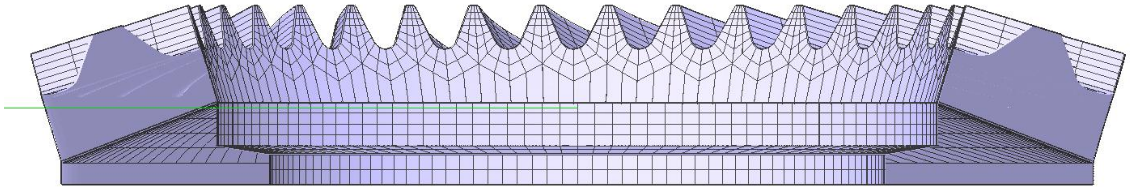


Figure 5.63 The hypoid model

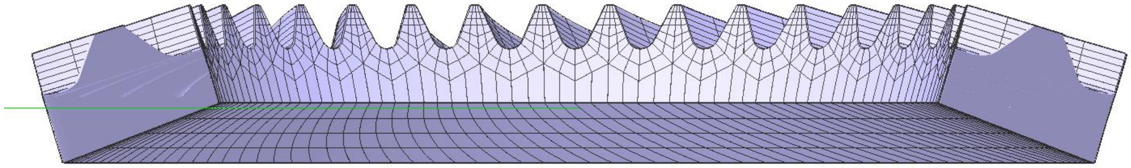


Figure 5.64 The hypoid gear tooth mesh

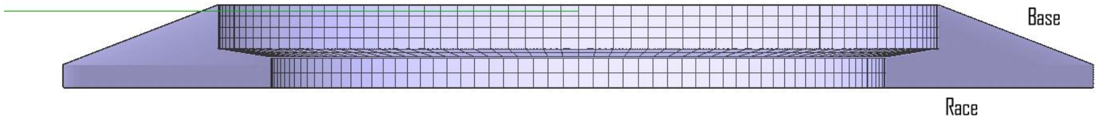
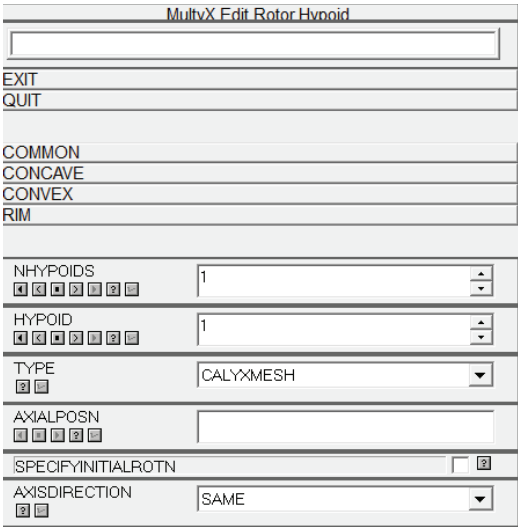


Figure 5.65 The hypoid rim mesh, showing the ‘Base’ and ‘Race’ surfaces of the hypoid model.


MultyX Edit Rotor Hypoid
EXIT
QUIT
COMMON
CONCAVE
CONVEX
RIM

NHYPOIDS 1

HYPOID 1

TYPE CALYXMESH

AXIALPOSN

SPECIFYINITIALROTN ☐

AXISDIRECTION SAME

Figure 5.66 The Hypoid gear menu.

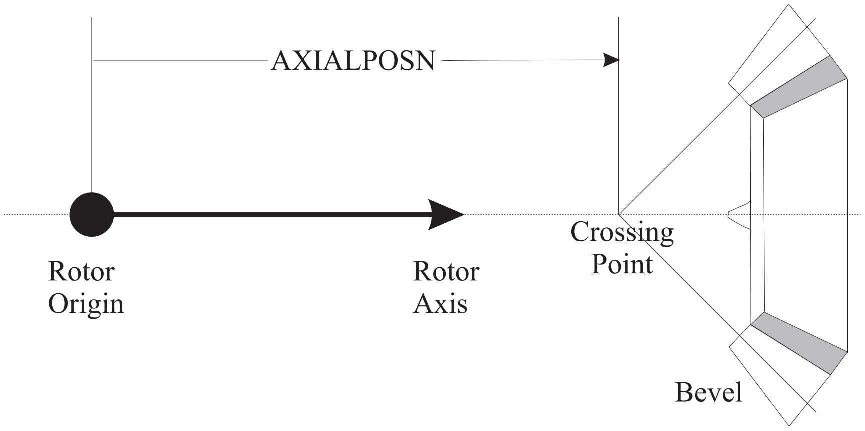

AXIALPOSN
Rotor Origin
Rotor Axis
Crossing Point
Bevel

Figure 5.67 Positioning of the bevel gear with respect to the rotor when AXISDIRECTION is set to SAME.

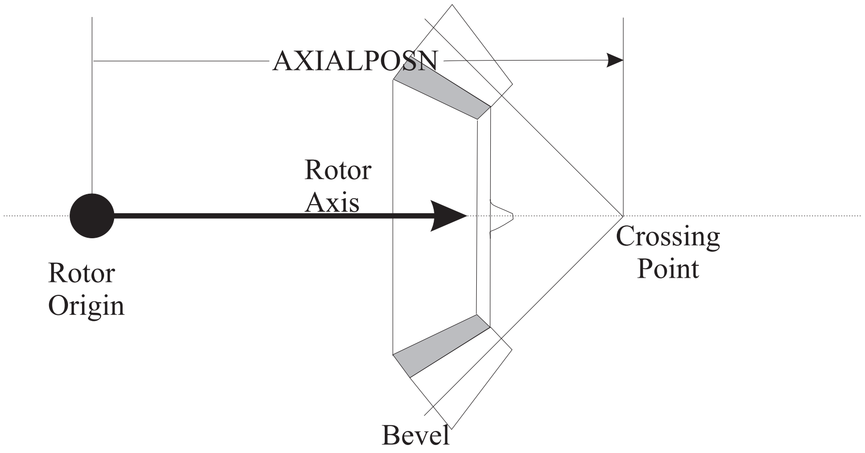
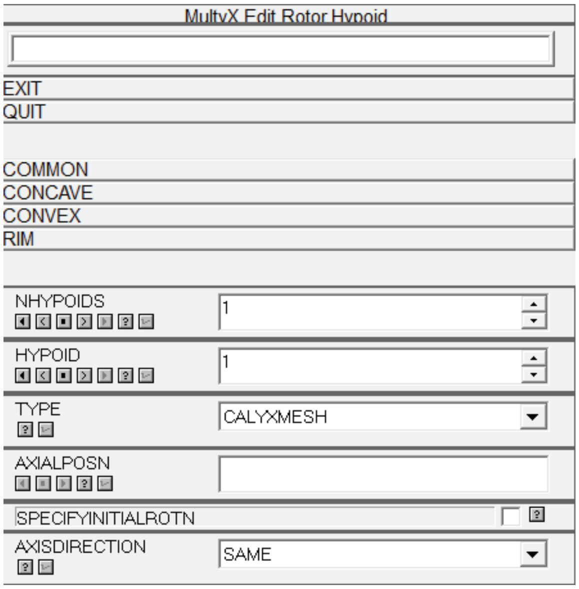

AXIALPOSN
Rotor Axis
Rotor Origin
Crossing Point
Bevel

Figure 5.68 Positioning of the bevel gear with respect to the rotor when AXISDIRECTION is set to OPPOSITE.



NHYPOIDS 1

HYPOID 1

TYPE CALYXMESH

AXIALPOSN

SPECIFYINITIALROTN ☐

AXISDIRECTION SAME

Figure 5.69 The hypoid pinion data menu.

5.7.1 FACMILLED and FACEHOBBED Tooth Types

The FACEMILLED and FACEHOBBED tooth types allows us to model the hypoid pinion and gear within the menu structure. Figure 5.69 shows the HYPOID menu for the face milled or face hobbed types. The menu has 5 submenus- SPAFILE (file name and unit system), COMMON(common design and blank data), CONCAVE(concave side data), CONVEX(convex side data) and RIM(rim data). Selecting the FACEMILLED_GEAR or FACEHOBBED_GEAR allows us to model a hypoid gear, while FACEMILLED_PINION and FACEHOBBED_PINION options are available for modeling the pinion. The gear menus are similar to the pinion menus except for the feature TYPE input, which decides whether the gear type is Generated or Formate. For a Formate gear the ratio of rolls(ratio of number of teeth on the imaginary gear to the number of teeth on the gear being cut) is zero in the Special Analysis File. For a Generated type this value is non-zero.

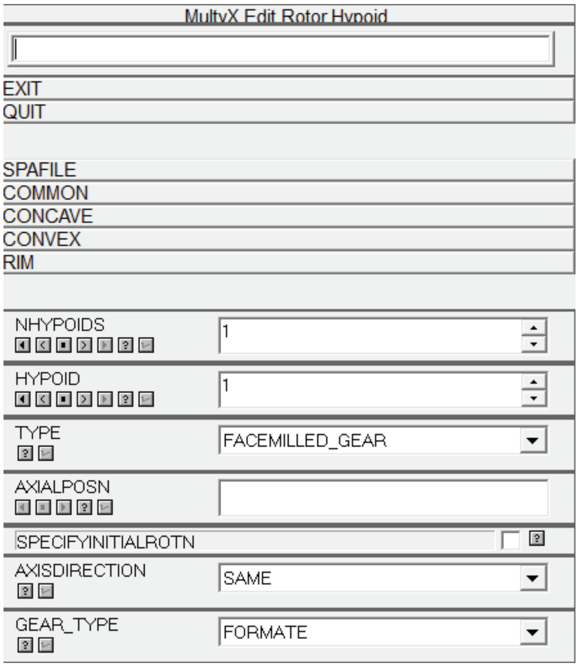
5.7.1.1 Common Design and Blank Data The COMMON command in Figure 5.69 leads to the common design and blank data menu shown in Figure 5.71. The common design and blank data for the gear is similar to that of the pinion. The various parameters for this menu are explained in Table 5.24 & Table 5.25

By default the thickness will be assumed to be defined at the ‘mean point’ (the intersection of the mid-face cone) with the pitch cone. This is the normal chordal tooth thickness (measured along the normal plane). The normal chordal tooth thickness is related to the transverse thickness by the following relationship.

$$\text{Normal chordal tooth thickness} \quad = \quad \text{Transverse chordal tooth thickness} \times \cos(\text{spiral angle})$$

If the SPECIFYMSRPT item is turned on, then the thickness can be specified at a point at an arbitrary ‘measuring addendum’ distance from the tip at mid-face as shown in Figure 5.72. The special analysis file does not include the measuring addendum or tooth thickness information. These inputs can be obtained from the Gleason summary sheet. Figure 5.73 shows how the data looks in the summary sheet.

The face angle, back angle, front angle, spiral angle and pitch angle values are given in radians in the Special Analysis File. The user should convert them in to degrees before entering them in their respective menus. If the ISRACERIGID flag is set, then the inner diameter of the pinion/gear is assumed to behave like a rigid cylinder. If it is not rigid then the bearing race is modelled using Fourier shape function in the circular direction. The Rayleigh damping model assumes that the damping matrix C for a finite element is related to the mass matrix M and stiffness matrix K by the linear relationship C= alpha*M + beta*K. The



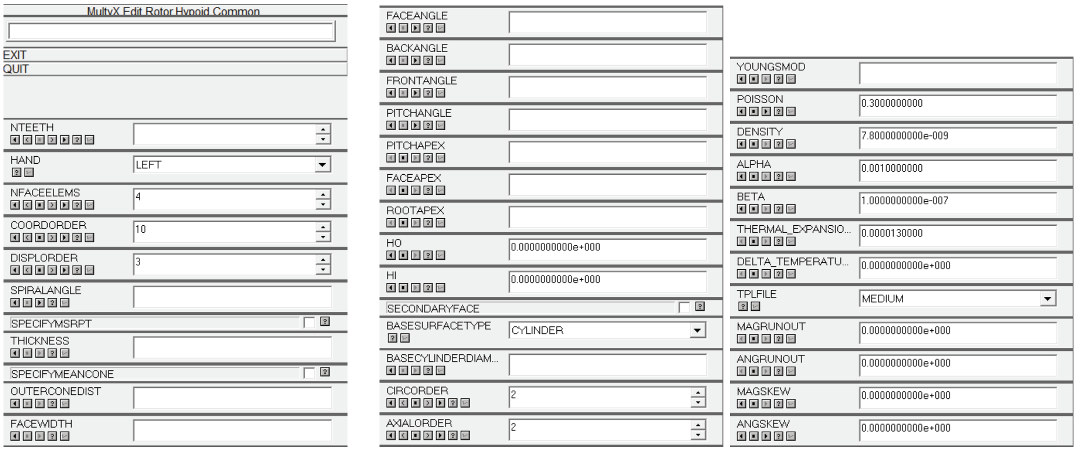
MultyX Edit Rotor Hypoid

EXIT
QUIT

SPAFILE
COMMON
CONCAVE
CONVEX
RIM

NHYPOIDS	1
HYPOID	1
TYPE	FACEMILLED_GEAR
AXIALPOSN	
SPECIFYINITIALROTN	☐
AXISDIRECTION	SAME
GEAR_TYPE	FORMATE

Figure 5.70 The hypoid gear data menu.



MultyX Edit Rotor Hypoid Common

EXIT
QUIT

NTEETH	
HAND	LEFT
NFACEELEMS	4
COORDORDER	10
DISPLORDER	3
SPIRALANGLE	
SPECIFYMSRPT	☐
THICKNESS	
SPECIFYMEANCONE	☐
OUTERCONEDIST	
FACEWIDTH	

FACEANGLE	
BACKANGLE	
FRONTANGLE	
PITCHANGLE	
PITCHAPEX	
FACEAPEX	
ROOTAPEX	
HO	0.0000000000e+000
HI	0.0000000000e+000
SECONDARYFACE	☐
BASESURFACETYPE	CYLINDER
BASECYLINDERDIAM...	
CIRCORDER	2
AXIALORDER	2

YOUNGSMOD	
POISSON	0.3000000000
DENSITY	7.8000000000e-009
ALPHA	0.0010000000
BETA	1.0000000000e-007
THERMAL_EXPANSIO...	0.0000130000
DELTA_TEMPERATU...	0.0000000000e+000
TPLFILE	MEDIUM
MAGRUNOUT	0.0000000000e+000
ANGRUNOUT	0.0000000000e+000
MAGSKEW	0.0000000000e+000
ANGSKEW	0.0000000000e+000

Figure 5.71 The common design and blank data menu.

Table 5.24 Common design and blank parameters

Item	Description	Special Analyis File Details
NTEETH	Integer, Number of teeth on the pinion/gear	Pinion-Record#1,Item#1 & Gear-Record#1,Item#2
NFACEELEMENTS	Integer, Number of elements across the face width of the pinion/gear	
COORDORDER	Integer, Limit on the order of coordinate axodes for the pinion/gear	
DISPLORDER	Integer, Limit on displ order of axodes	
SPIRALANGLE	Float, Angle between the tooth trace and an element of the pitch cone(Deg)	Pinion-Record#1,Item#10 & Gear-Record#8,Item#4
SPECIFYMSRPT	Boolean, Whether to specify the thickness measuring point	
MEASADDENDUM	Float, The measuring addendum	
THICKNESS	Float, Mean transverse tooth thickness	Pinion-Record#47,Item#7 & Gear-Record#47,Item#8
OUTERCONEDIST	Float, Distance from the apex of the pitch cone to the outer ends of the tooth	Pinion-Record#3,Item#9 & Gear-Record#3,Item#10
FACEWIDTH	Float, Face width of the tooth	Pinion-Record#1,Item#6 & Gear-Record#1,Item#5
FACEANGLE	Float, Angle between the element of the face cone and axis(Deg)	Pinion-Record#5,Item#6 & Gear-Record#7,Item#6
BACKANGLE	Float, Angle between the element of the back cone and the plane perpendicular to the axis of rotation(Deg)	Pinion-Record#5,Item#9 & Gear-Record#7,Item#9
FRONTANGLE	Float,Angle between the element of the front cone and the plane perpendicular to the axis of rotation(Deg)	Pinion-Record#5,Item#10 & Gear-Record#7,Item#10
PITCHANGLE	Float, Angle between the element of the pitch cone and axis(Deg)	Pinion-Record#5,Item#5 & Gear-Record#7,Item#5
PITCHAPEX	Float, Pitch apex beyond crossing point distance	Pinion-Record#5,Item#15 & Gear-Record#7,Item#15
FACEAPEX	Float, Face apex beyond crossing point distance	Pinion-Record#4,Item#3 & Gear-Record#4,Item#4
ROOTAPEX	Float, Root apex beyond the crossing point distance	Pinion-Record#5,Item#12 & Gear-Record#7,Item#12

Table 5.25 Common design and blank parameters

Item	Description	Special Analyis File Details
BASESURFACETYPE	Switch, Kind of surface to be used as the base surface(CYLINDER/CONE)	
BASECYLINDERDIAME	Float, Diameter of the cylinder used as the base of the tooth mesh(IF BASESURFACETYPE=CYLINDER)	
BASECONEANGLE	Float, Angle(Deg) between the element of the base cone and the axis(IF BASESURFACETYPE=CONE)	
BASECONEAPEX	Float, Inner cone apex beyond crossing point distance(IF BASESURFACETYPE=CONE)	
ISRACERIGID	Boolean, Whether the bearing race is a rigid surface	
AXIALORDER	Integer, Polynomial order in the face direction	
CIRCORDER	Integer, Fourier series order in the circular direction	
YOUNGSMOD	Float, Youngs modulus for the pinion/gear	
POISSON	Float, Poisson’s ratio for the pinion/gear	
DENSITY	Float, Density of the pinion/gear	
ALPHA	Float, Damping constant alpha for the pinion/gear	
BETA	Float, Damping constant beta for the pinion/gear	
TPLFILE	Switch, Template file for the pinion/gear(Refer to appendix for details)	
MESHFILE	String, Mesh file name for the pinion/gear	

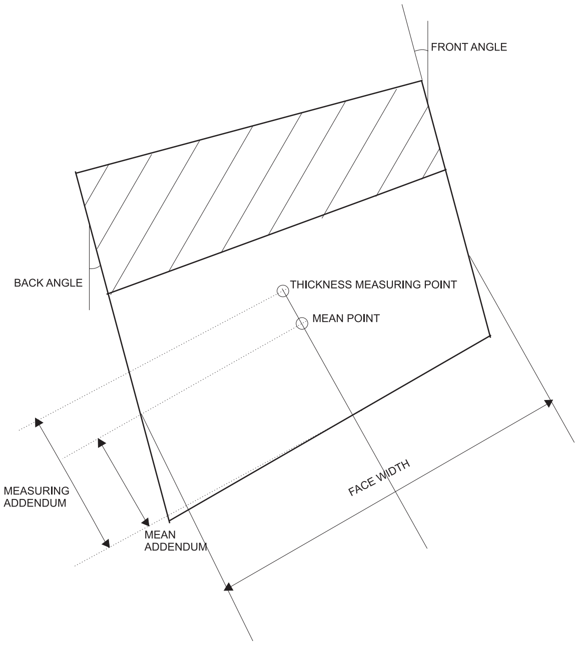
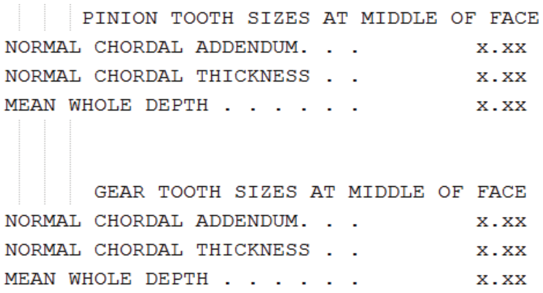

FRONT ANGLE
BACK ANGLE
THICKNESS MEASURING POINT
MEAN POINT
MEASURING ADDENDUM
MEAN ADDENDUM
FACE WIDTH

Figure 5.72 Thickness measurement at an arbitrary point.



```
      PINION TOOTH SIZES AT MIDDLE OF FACE
NORMAL CHORDAL ADDENDUM. . .         x.xx
NORMAL CHORDAL THICKNESS . .         x.xx
MEAN WHOLE DEPTH . . . . . .         x.xx


       GEAR TOOTH SIZES AT MIDDLE OF FACE
NORMAL CHORDAL ADDENDUM. . .         x.xx
NORMAL CHORDAL THICKNESS . .         x.xx
MEAN WHOLE DEPTH . . . . . .         x.xx
```

Figure 5.73 Tooth thickness and measuring addendum information in Gleason summary sheet.

variables ALPHA and BETA in the common data menu are the values of alpha and beta respectively in the above equation.The MESHFILE which contains the element connectivity and the geometrical information is created by the program. Figure 5.74 shows the Pinion common parameters. Figure 5.75 shows the Gear common parameters.

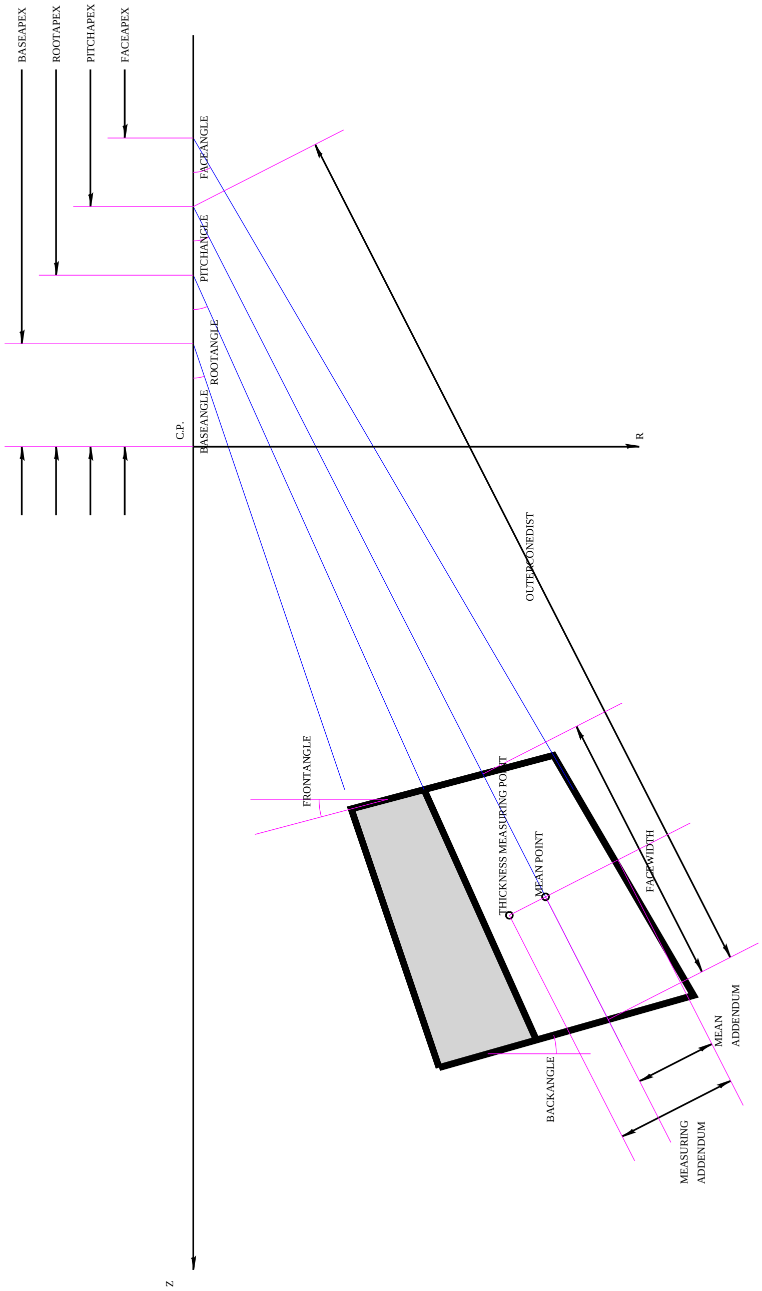

BASEAPEX
ROOTAPEX
PITCHAPEX
FACEAPEX
FACEANGLE
PITCHANGLE
ROOTANGLE
BASEANGLE
C.P.
R
OUTERCONEDIST
FRONTANGLE
THICKNESS MEASURING POINT
MEAN POINT
FACEWIDTH
MEAN ADDENDUM
BACKANGLE
MEASURING ADDENDUM
Z

Figure 5.74 The Pinion Common Parameters.

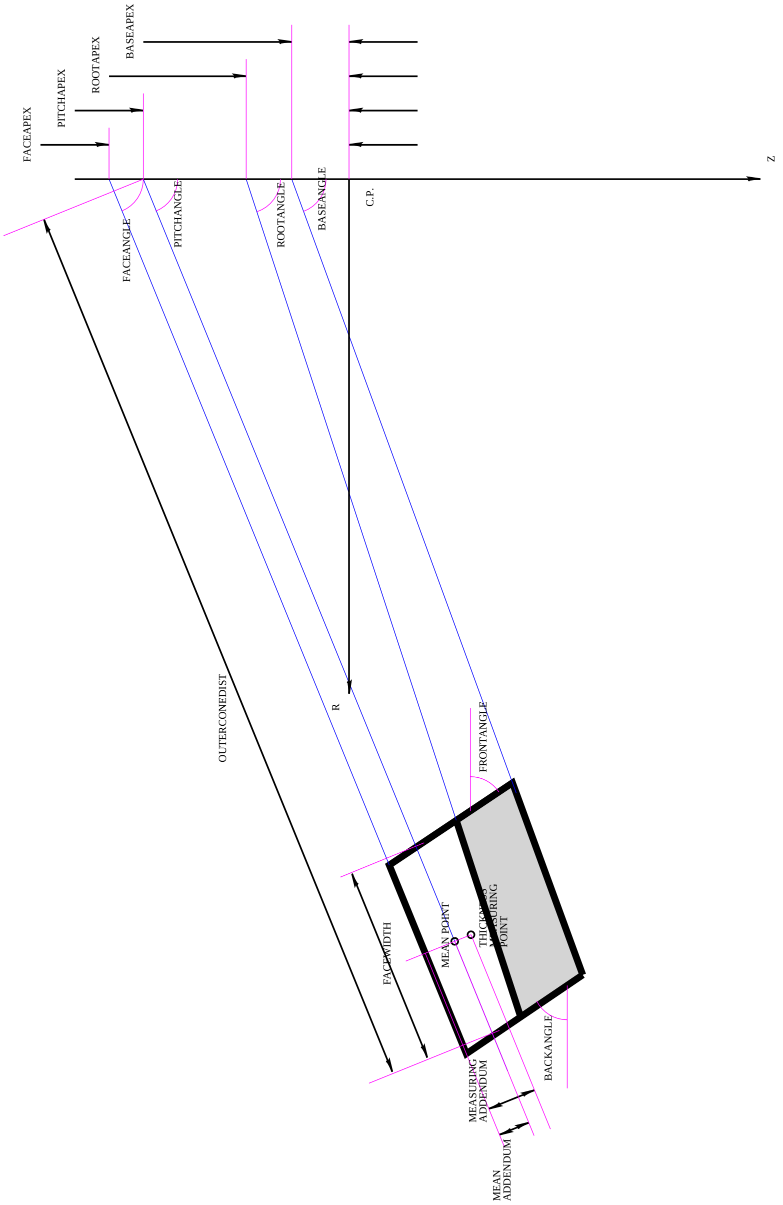

FACEAPEX
PITCHAPEX
ROOTAPEX
BASEAPEX
Z
FACEANGLE
PITCHANGLE
ROOTANGLE
BASEANGLE
C.P.
OUTERCONEDIST
R
FRONTANGLE
FACEWIDTH
MEAN POINT
THICKNESS MEASURING POINT
BACKANGLE
MEASURING ADDENDUM
MEAN ADDENDUM

Figure 5.75 The Gear Common Parameters.

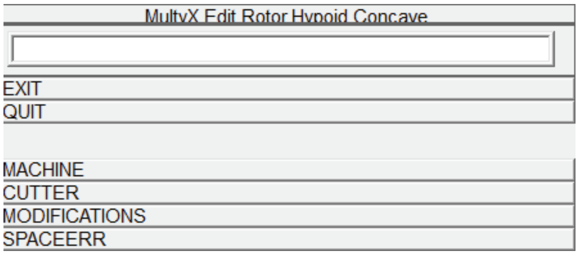

MultyX Edit Rotor Hypoid Concave
EXIT
QUIT
MACHINE
CUTTER
MODIFICATIONS
SPACEERR

Figure 5.76 The Concave tooth side data menu.

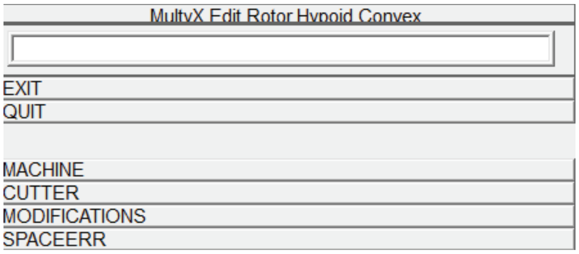
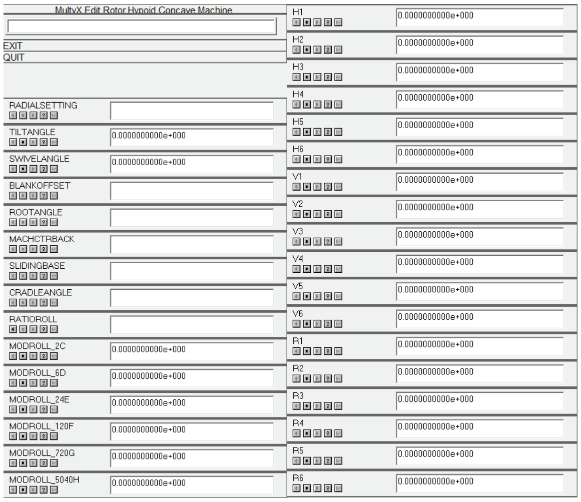

MultyX Edit Rotor Hypoid Convex
EXIT
QUIT
MACHINE
CUTTER
MODIFICATIONS
SPACEERR

Figure 5.77 The Convex tooth side data menu.


MultyX Edit Rotor Hypoid Concave Machine
EXIT
QUIT

RADIALSETTING	
TILTANGLE	0.0000000000e+000
SWIVELANGLE	0.0000000000e+000
BLANKOFFSET	
ROOTANGLE	
MACHCTRBACK	
SLIDINGBASE	
CRADLEANGLE	
RATIOROLL	
MODROLL_2C	0.0000000000e+000
MODROLL_6D	0.0000000000e+000
MODROLL_24E	0.0000000000e+000
MODROLL_120F	0.0000000000e+000
MODROLL_720G	0.0000000000e+000
MODROLL_5040H	0.0000000000e+000
H1	0.0000000000e+000
H2	0.0000000000e+000
H3	0.0000000000e+000
H4	0.0000000000e+000
H5	0.0000000000e+000
H6	0.0000000000e+000
V1	0.0000000000e+000
V2	0.0000000000e+000
V3	0.0000000000e+000
V4	0.0000000000e+000
V5	0.0000000000e+000
V6	0.0000000000e+000
R1	0.0000000000e+000
R2	0.0000000000e+000
R3	0.0000000000e+000
R4	0.0000000000e+000
R5	0.0000000000e+000
R6	0.0000000000e+000

Figure 5.78 Machine parameters

5.7.1.2 Concave and Convex Side Data The CONCAVE and CONVEX command in the pinion menu leads to the concave and convex side data menus shown in Figures 5.76 & 5.77 . There are four submenus-MACHINE, CUTTER, MODIFICATIONS, and SPACEERR. All four data submenus are similar for both the concave and convex side data except that the data comes from a different part of the Special Analysis File. For the generated type gear the data menus for concave and convex side gear tooth are similar to those for the pinion. They are slightly different for the formate type gear.

Machine Settings for the Pinion The MACHINE command in Figures 5.76 & 5.77 leads to the details of the face milling operation settings used for the manufacturing of the hypoid pinion/gear shown in Figure 5.78. Table 5.26 explains all the machine parameters in this menu.

Table 5.26 Machine parameters for concave and convex tooth side for the pinion

Item	Description	Special Analyis File Details
RADIALSETTING	Float, Distance between the cradle axis and the cutter axis when they are parallel	Concave side-Record#15,Item#1 & Convex side-Record#18,Item#1
TILTANGLE	Float, Tilt of the cutter axis with respect to the direction of the cradle axis(Deg)	Concave side-Record#15,Item#2 & Convex side-Record#18,Item#2
SWIVELANGLE	Float, Direction of the cutter spindle tilt with respect to the gear being generated(Deg)	Concave side-Record#15,Item#3 & Convex side-Record#18,Item#3
BLANKOFFSET	Float, Offset between the work spindle axis and the cradle axis	Concave side-Record#15,Item#4 & Convex side-Record#18,Item#4
ROOTANGLE	Float, Angle between the element of the root cone and its axis(Deg)	Concave side-Record#15,Item#5 & Convex side-Record#18,Item#5
MACHCTRBACK	Float, Axial distance from the root apex of the gear to the spindle mounting surface	Concave side-Record#15,Item#6 & Convex side-Record#18,Item#6
SLIDINGBASE	Float, Position of the sliding base with respect to the machine plane	Concave side-Record#15,Item#7 & Convex side-Record#18,Item#7
CRADLEANGLE	Float, Angular position of the cradle axis with respect to the gear generated	Concave side-Record#16,Item#9 & Convex side-Record#19,Item#9
RATIOROLL	Float, Ratio of the number of teeth on the imaginary gear to the number of teeth on the gear being cut	Concave side-Record#15,Item#13 & Convex side-Record#18,Item#13
2C	Float, Modified roll 2nd order coefficient	Concave side-Record#15,Item#14 & Convex side-Record#18,Item#14
6D	Float, Modified roll 3rd order coefficient	Concave side-Record#15,Item#15 & Convex side-Record#18,Item#15
24E	Float, Modified roll 4th order coefficient	Concave side-Record#16,Item#1 & Convex side-Record#19,Item#1
120F	Float, Modified roll 5th order coefficient	Concave side-Record#16,Item#2 & Convex side-Record#19,Item#2
H1	Float, Helical motion 1st order coefficient	Concave side-Record#16,Item#3 & Convex side-Record#19,Item#3
H2	Float, Helical motion 2nd order coefficient	Concave side-Record#16,Item#4 & Convex side-Record#19,Item#4
H3	Float, Helical motion 3rd order coefficient	Concave side-Record#16,Item#5 & Convex side-Record#19,Item#5
V1	Float, Vertical motion 1st order coefficient	Concave side-Record#16,Item#6 & Convex side-Record#19,Item#6
V2	Float, Vertical motion 2nd order coefficient	Concave side-Record#16,Item#7 & Convex side-Record#19,Item#7
V3	Float, Vertical motion 3rd order coefficient	Concave side-Record#16,Item#8 & Convex side-Record#19,Item#8

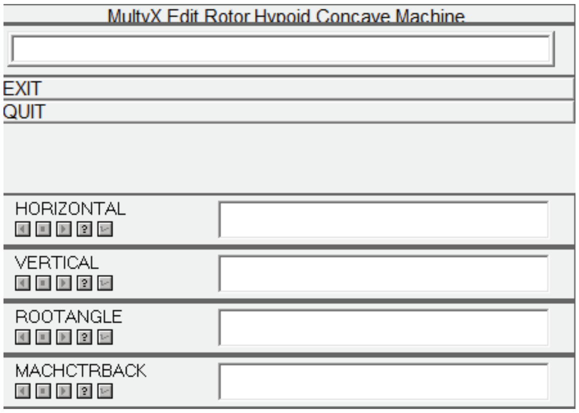


Figure 5.79 Machine parameters for formate gear

The values for Tiltangle, Swivelangle, Rootangle, and the Cradleangle are given in radians in the Special Analysis File. The user should convert them in to degrees before entering them in to their respective menus.

Machine Settings for the Generated Type Gear All the parameters for the machine details specifications for the generated type gear are similar to those of the pinion (Figure 5.78), except for the record numbers in the Special Analyis File. Table 5.27 explains all the parameters for the Machine menu for the generated type gear. Again,the values for Tiltangle, Swivelangle, Rootangle, and the Cradleangle are given in radians in the Special Analysis File. The user should convert them in to degrees before entering them in to their respective menus.

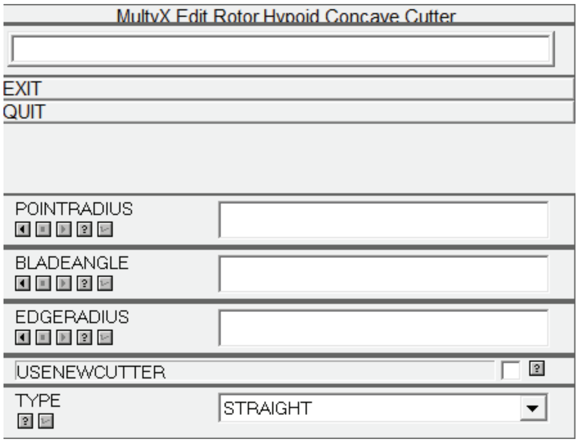
Machine Settings for the Formate Type Gear Figure 5.79 shows the machine parameters for the concave side of the formate type gear. The parameters for the convex side are similar to those of the concave side. The Root angle value is given in radians in the Special Analysis File. The user should convert it in to degrees before entering it in the Rootangle menu. Table 5.28 explains all the machine parameters associated with the manufacturing of the formate gear.

Table 5.27 Machine parameters for concave and convex tooth side for the generated type gear

Item	Description	Special Analyis File Details
RADIALSETTING	Float, Distance between the cradle axis and the cutter axis when they are parallel	Concave side-Record#25,Item#1 & Convex side-Record#21,Item#1
TILTANGLE	Float, Tilt of the cutter axis with respect to the direction of the cradle axis(Deg)	Concave side-Record#25,Item#2 & Convex side-Record#21,Item#2
SWIVELANGLE	Float, Direction of the cutter spindle tilt with respect to the gear being generated(Deg)	Concave side-Record#25,Item#3 & Convex side-Record#21,Item#3
BLANKOFFSET	Float, Offset between the work spindle axis and the cradle axis	Concave side-Record#25,Item#4 & Convex side-Record#21,Item#4
ROOTANGLE	Float, Angle between the element of the root cone and its axis(Deg)	Concave side-Record#25,Item#5 & Convex side-Record#21,Item#5
MACHCTRBACK	Float, Axial distance from the root apex of the gear to the spindle mounting surface	Concave side-Record#25,Item#6 & Convex side-Record#21,Item#6
SLIDINGBASE	Float, Position of the sliding base with respect to the machine plane	Concave side-Record#25,Item#7 & Convex side-Record#21,Item#7
CRADLEANGLE	Float, Angular position of the cradle axis with respect to the gear generated	Concave side-Record#26,Item#9 & Convex side-Record#22,Item#9
RATIOROLL	Float, Ratio of the number of teeth on the imaginary gear to the number of teeth on the gear being cut	Concave side-Record#25,Item#13 & Convex side-Record#21,Item#13
2C	Float, Modified roll 2nd order coefficient	Concave side-Record#25,Item#14 & Convex side-Record#21,Item#14
6D	Float, Modified roll 3rd order coefficient	Concave side-Record#25,Item#15 & Convex side-Record#21,Item#15
24E	Float, Modified roll 4th order coefficient	Concave side-Record#26,Item#1 & Convex side-Record#22,Item#1
120F	Float, Modified roll 5th order coefficient	Concave side-Record#26,Item#2 & Convex side-Record#22,Item#2
H1	Float, Helical motion 1st order coefficient	Concave side-Record#26,Item#3 & Convex side-Record#22,Item#3
H2	Float, Helical motion 2nd order coefficient	Concave side-Record#26,Item#4 & Convex side-Record#22,Item#4
H3	Float, Helical motion 3rd order coefficient	Concave side-Record#26,Item#5 & Convex side-Record#22,Item#5
V1	Float, Vertical motion 1st order coefficient	Concave side-Record#26,Item#6 & Convex side-Record#22,Item#6
V2	Float, Vertical motion 2nd order coefficient	Concave side-Record#26,Item#7 & Convex side-Record#22,Item#7
V3	Float, Vertical motion 3rd order coefficient	Concave side-Record#26,Item#8 & Convex side-Record#22,Item#8

Table 5.28 Machine parameters for the formate gear

Item	Description	Special Analyis File Details
HORIZONTAL	Float, Horizontal setting of the cutter	Concave side-Record#28,Item#2 & Convex side-Record#24,Item#2
VERTICAL	Float, Vertical setting of the cutter	Concave side-Record#28,Item#1 & Convex side-Record#24,Item#1
ROOTANGLE	Float, Angle between the element of the root cone and its axis(Deg)	Concave side-Record#28,Item#4 & Convex side-Record#24,Item#4
MACHCTRBACK	Float, Axial distance from the root apex of the gear to the spindle mounting distance	Concave side-Record#28,Item#3 & Convex side-Record#24,Item#3



USENEWCUTTER ☐

TYPE STRAIGHT

Figure 5.80 Cutter specifications for the pinion

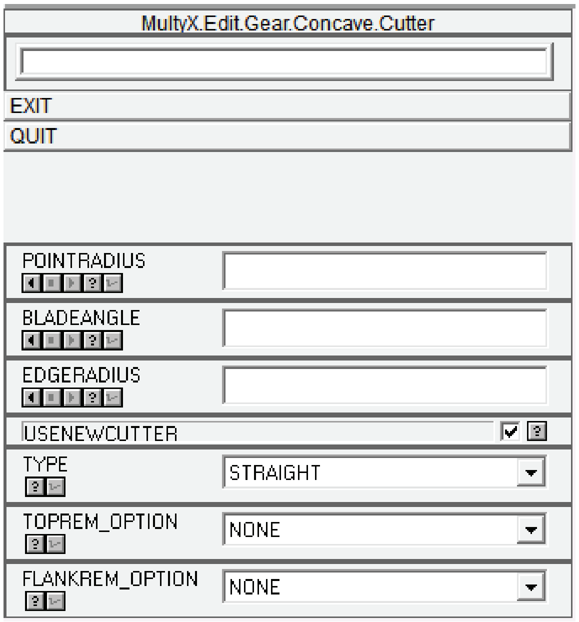
Cutter Specifications for the Pinion The CUTTER command in Figures 5.76 & 5.77 leads to the cutter menu shown in Figure 5.80. Table 5.29 gives the Special Analysis File details for the Cutter menu.

Cutter point radius is the radius of the cutter in a plane perpendicular to the cutter axis of rotation and passing through the tips of the blades. The special analysis file gives the blade angle(angle between the cutting edge of the cutter and the cutter axis of rotation) in radians. The user should convert that value in to degrees before entering it in to the BLADEANGLE menu. The value to be entered should always be positive. The sign for this item in the Special Analysis File can be disregarded.

Use new cutter If the USENEWCUTTER flag in Figure 5.80 is checked, then the menu will update to display the new cutter options, Figure 5.81. The new cutter menu has three sets of options: Type, Toprem Option and Flankrem Option. The default type of cutter is the STRAIGHT type and the default type of Toprem and Flankrem is NONE.

A cutter can have any combination of Toprem and Flankrem options. For both the choices are NONE, STRAIGHT and BLENDED. If a STRAIGHT Toprem or Flankrem is chosen then two new parameters (TOPREM_DEPTH or FLANKREM_DEPTH and TOPREMANGLE or FLANKREM_ANGLE) are added to the cutter menu. Figures 5.82 and 5.84 show the concave side cutter profile for STRAIGHT Toprem and Flankrem on a STRAIGHT blade type. If a BLENDED Toprem or Flankrem is chosen then two new parameters (TOPREM_DEPTH or FLANKREM_DEPTH and TOPREM_BLEND_RADIUS or FLANKREM_BLEND_RADIUS) are added to the cutter menu. Figures 5.83 and 5.85 show the concave side of the cutter profile with the appropriate parameters on a STRAIGHT blade type.

If the CURVED type cutter is selected then a parameter called RHO is added to the cutter menu. RHO is the spherical radius of the blade. If the STRAIGHT Toprem or Flankrem option is selected then a new parameter called DEDENDUM is added to the cutter menu. DEDENDUM is the distance from the mean point to the cutter tip, measured along the cutter axis (Z) direction. Figures 5.86 and 5.88 show the concave side cutter profile for STRAIGHT Toprem and Flankrem on a CURVED blade type. Figures 5.87 and 5.89 show the concave side of the cutter profile for BLENDED Toprem and Flankrem on a CURVED blade type.



MultyX.Edit.Gear.Concave.Cutter
EXIT
QUIT

POINTRADIUS

BLADEANGLE

EDGERADIUS

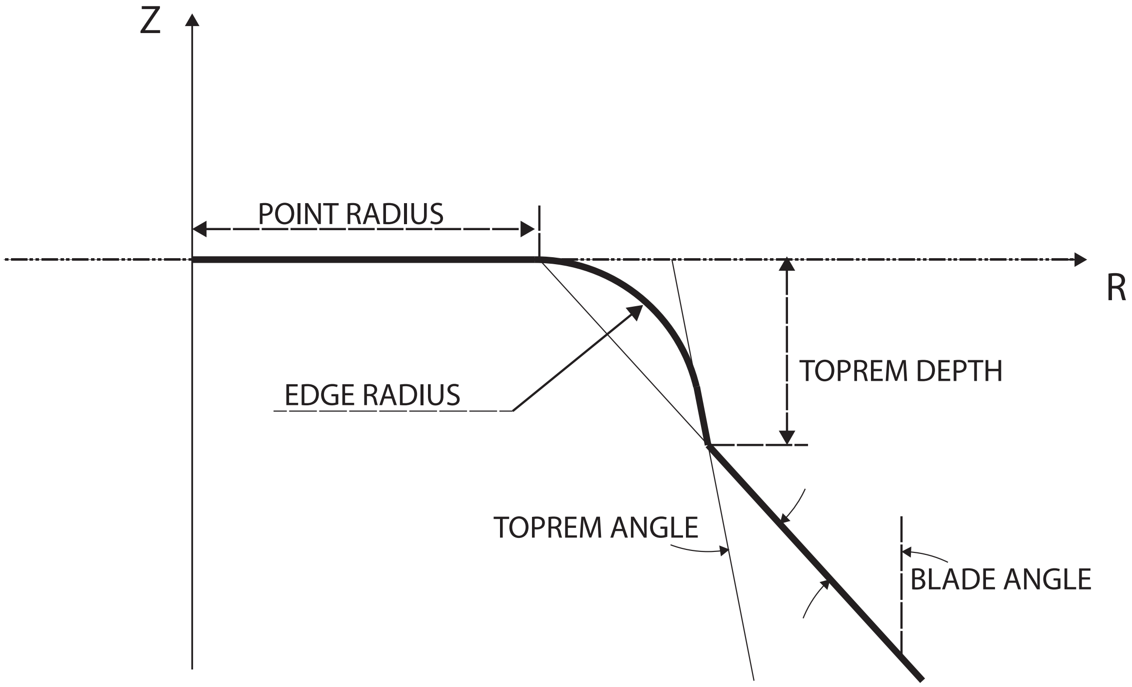
USENEWCUTTER ☑

TYPE: STRAIGHT

TOPREM_OPTION: NONE

FLANKREM_OPTION: NONE

Figure 5.81 Cutter specifications with USENWCUTTER flag checked



Z
R
POINT RADIUS
EDGE RADIUS
TOPREM DEPTH
TOPREM ANGLE
BLADE ANGLE

Figure 5.82 Cutter description for Straight Blade with Straight Toprem (New Cutter)

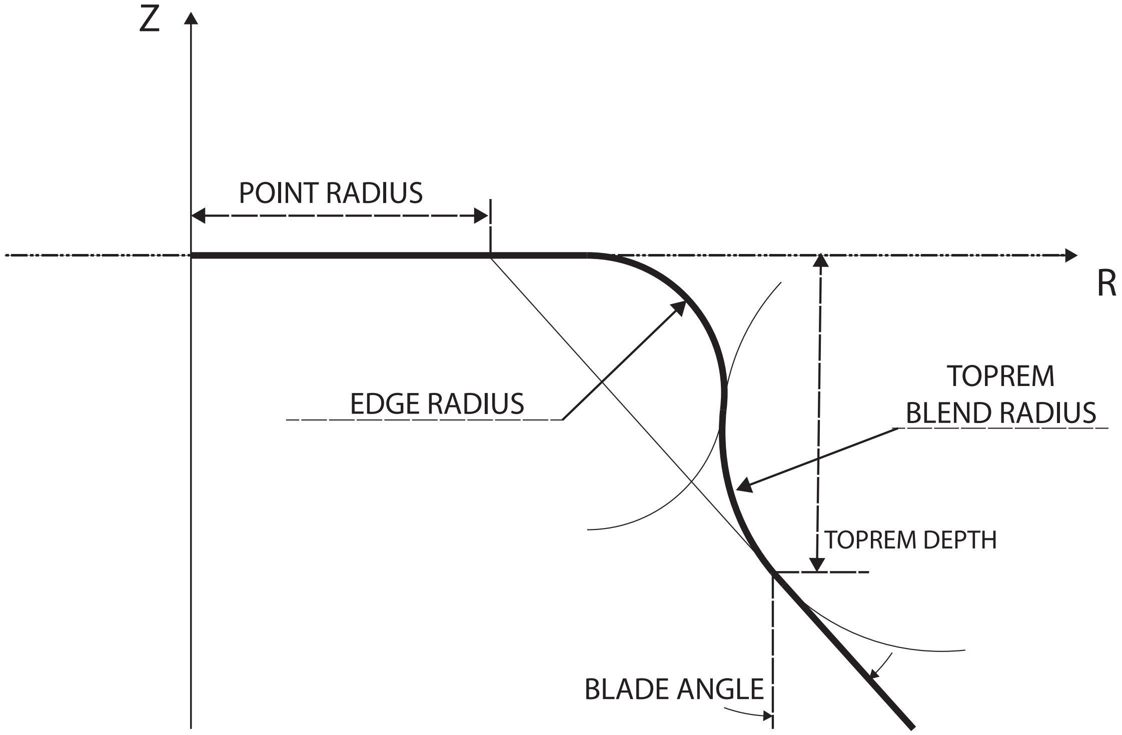

Z
POINT RADIUS
R
EDGE RADIUS
TOPREM
BLEND RADIUS
TOPREM DEPTH
BLADE ANGLE

Figure 5.83 Cutter description for Straight Blade with Blended Toprem (New Cutter)

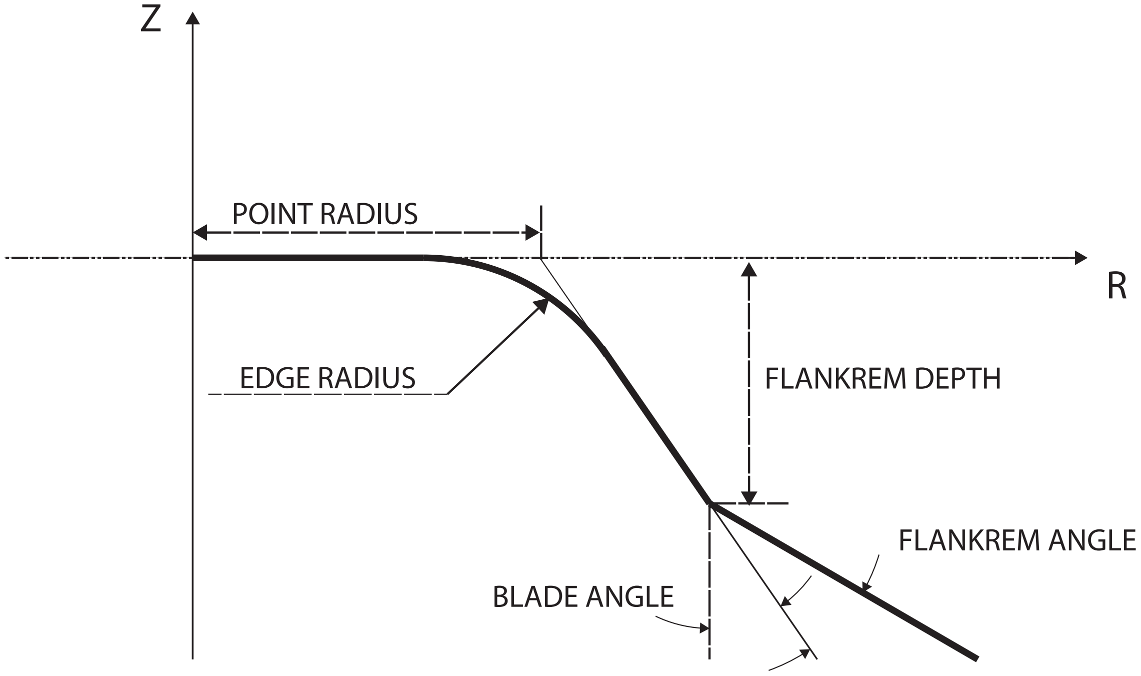

Z
POINT RADIUS
R
EDGE RADIUS
FLANKREM DEPTH
FLANKREM ANGLE
BLADE ANGLE

Figure 5.84 Cutter description for Straight Blade with Straight Flankrem (New Cutter)

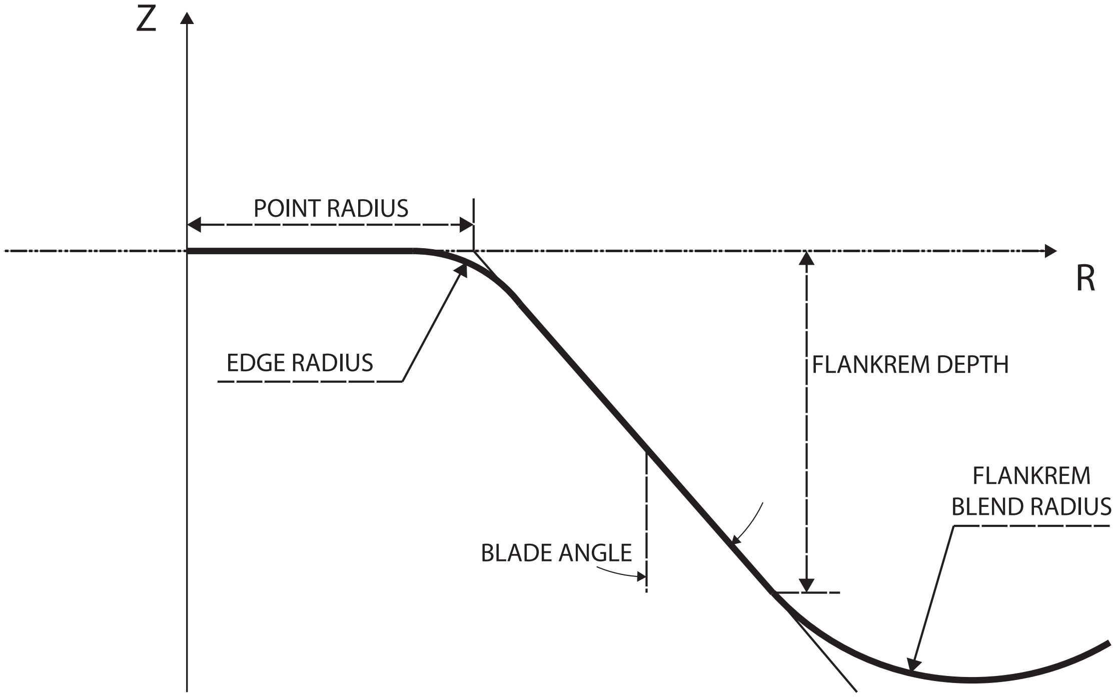

Z
POINT RADIUS
R
EDGE RADIUS
FLANKREM DEPTH
FLANKREM
BLEND RADIUS
BLADE ANGLE

Figure 5.85 Cutter description for Straight Blade with Blended Flankrem (New Cutter)

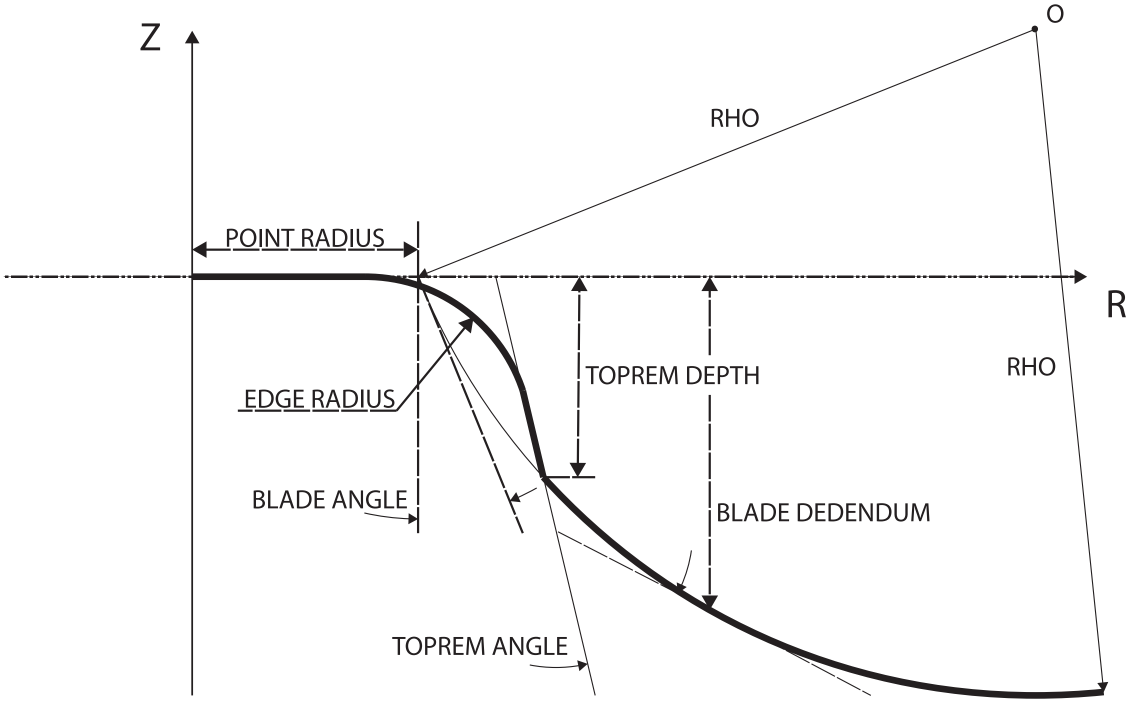

O
Z
RHO
POINT RADIUS
R
RHO
EDGE RADIUS
TOPREM DEPTH
BLADE ANGLE
BLADE DEDENDUM
TOPREM ANGLE

Figure 5.86 Cutter description for Curved Blade with Straight Toprem (New Cutter)

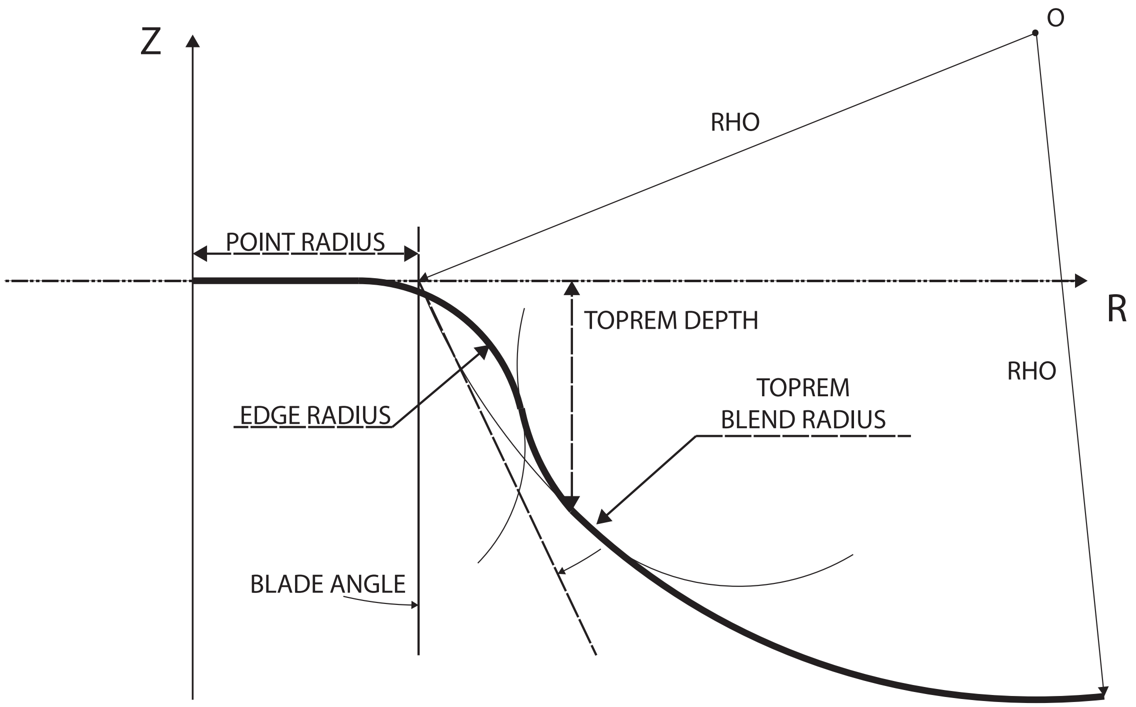

Z
O
RHO
POINT RADIUS
R
TOPREM DEPTH
RHO
TOPREM
BLEND RADIUS
EDGE RADIUS
BLADE ANGLE

Figure 5.87 Cutter description for Curved Blade with Blended Toprem (New Cutter)

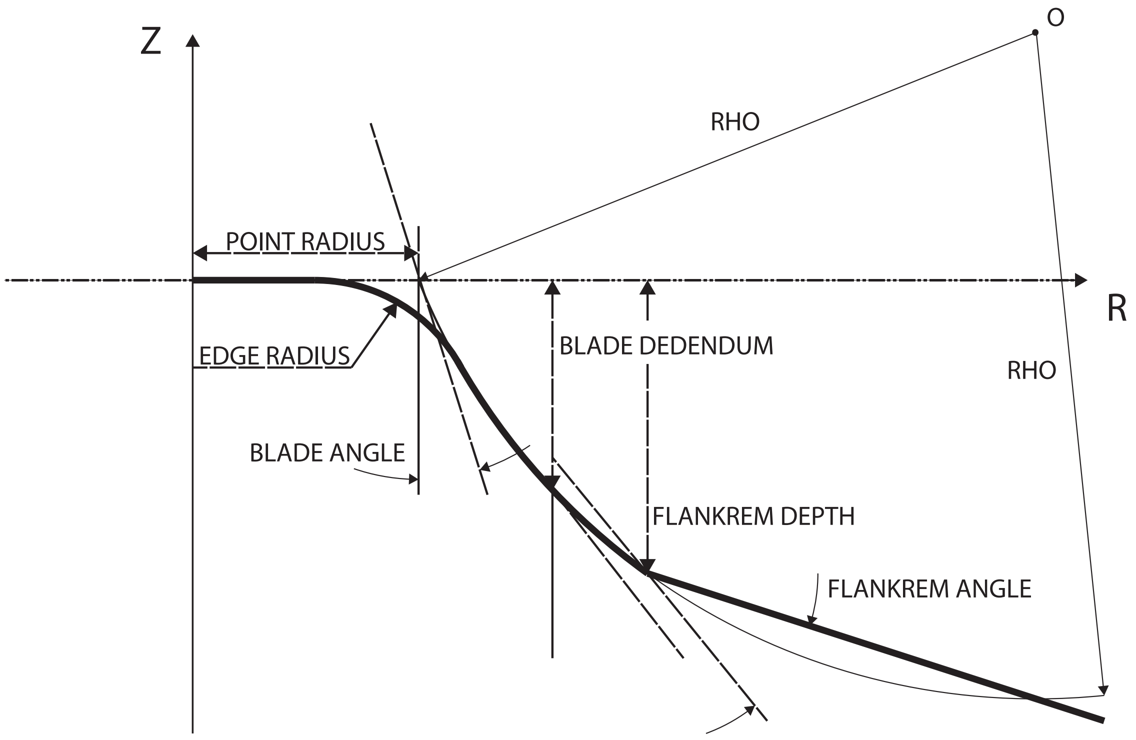

Z
O
RHO
POINT RADIUS
R
EDGE RADIUS
BLADE DEDENDUM
RHO
BLADE ANGLE
FLANKREM DEPTH
FLANKREM ANGLE

Figure 5.88 Cutter description for Curved Blade with Straight Flankrem (New Cutter)

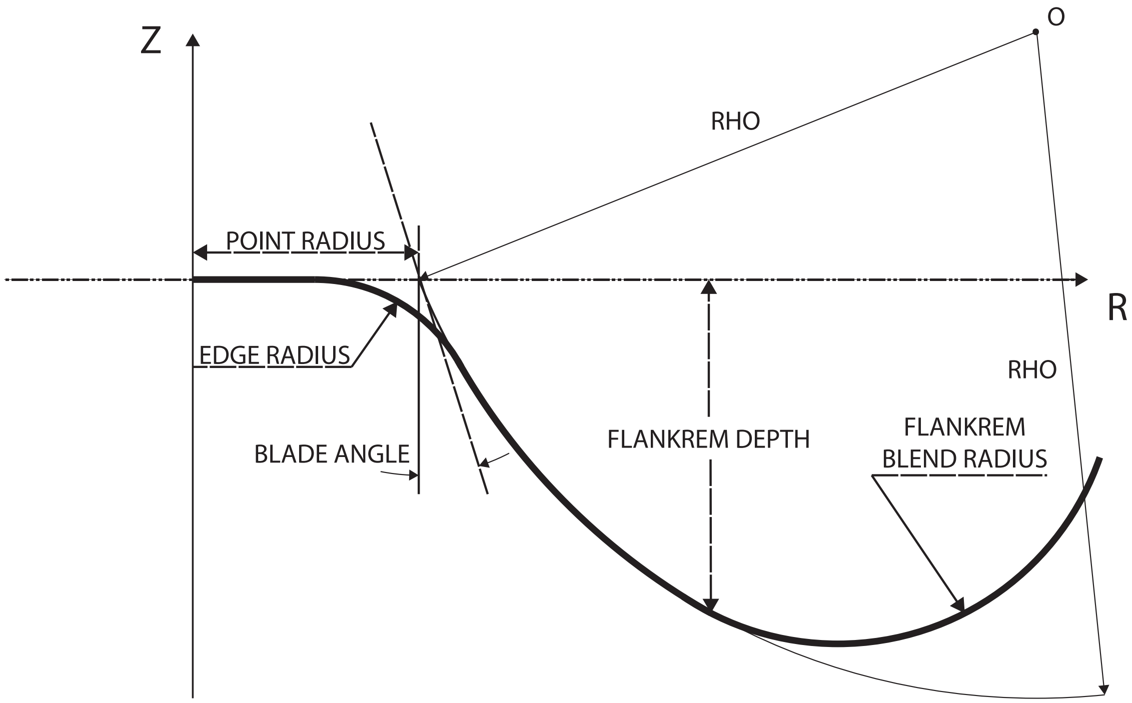

Z
O
RHO
POINT RADIUS
R
EDGE RADIUS
RHO
BLADE ANGLE
FLANKREM DEPTH
FLANKREM
BLEND RADIUS

Figure 5.89 Cutter description for Curved Blade with Blended Flankrem (New Cutter)

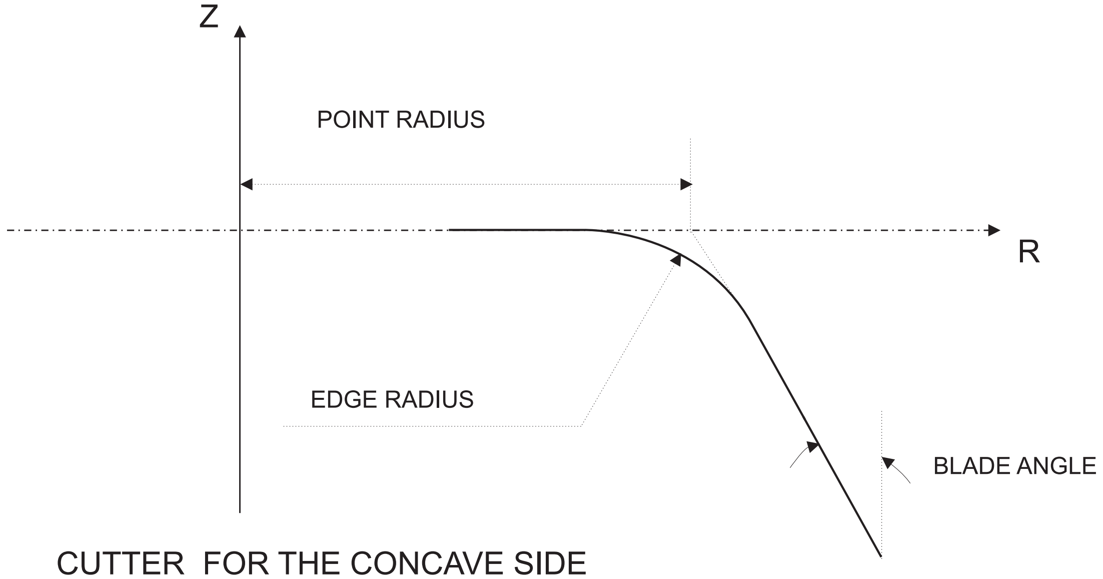
Table 5.29 Cutter specifications for concave and convex tooth side of a pinion

Item	Description	Special Analyis File Details
POINTRADIUS	Float, Radius of the cutter	Concave side-Record#17,Item#5 & Convex side-Record#20,Item#5
BLADEANGLE	Float, Cutter blade angle(Deg)	Concave side-Record#17,Item#4 & Convex side-Record#20,Item#4
EDGERADIUS	Float, Radius of the cutter edge(Tip radius)	Concave side-Record#16,Item#15 & Convex side-Record#19,Item#15
TYPE	Switch, Type of cutter(STRAIGHT/TOPREM)	Concave side-Record#17,Item#1 & Convex side-Record#20,Item#1

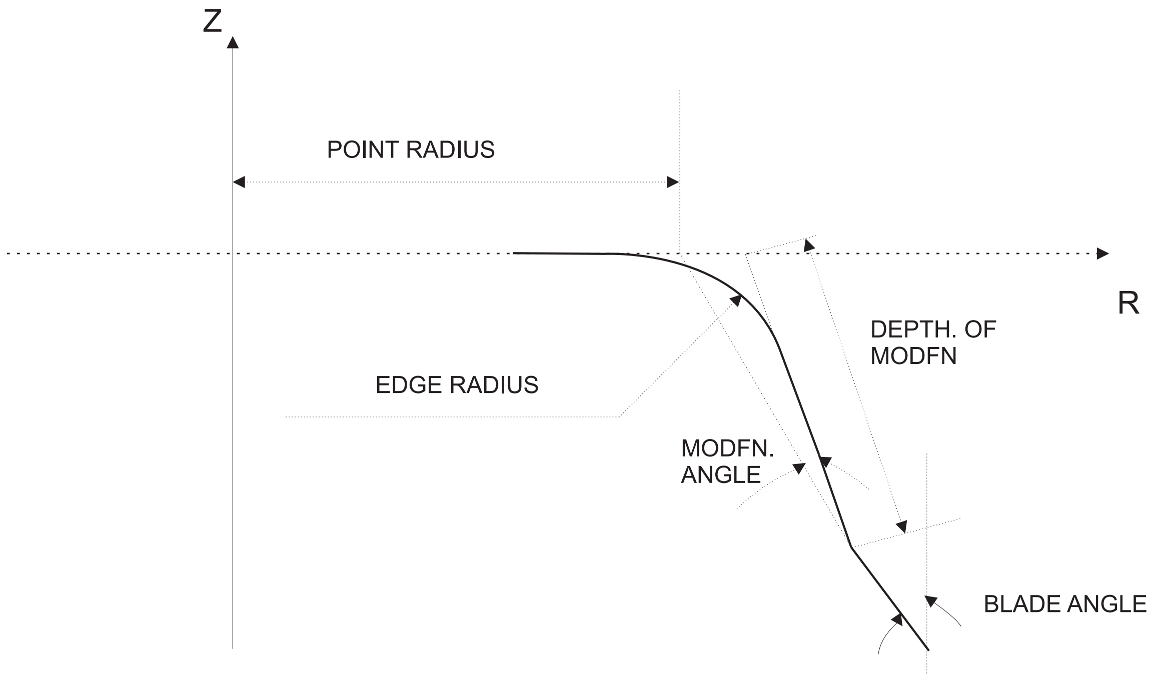
Use old cutter The default type of cutter is the STRAIGHT type, but if the TOPREM type is used then two more parameters (TOPREMANGLE and TOPREMLENGTH) are added to the cutter menu. TOPREMANGLE (Special Analysis File Record#17, Item#1 for Concave side and Record#20, Item#1 for Convex Side) is the angle that the modified part of the cutter makes with the unmodified part. When it is zero modification has no effect. A positive angle implies that the material is being added to the tip of the cutter. The value of this angle given in the Special Analysis File is in radians. The user should convert in to degress before entering it in the TOPREMANGLE menu. TOPREMLENGTH(Record#17, Item#2 for Concave side and Record#20, Item#2 for Convex side) is the distance from the cutter point of the start of the modified part of the cutter.

If the Special Analysis File Record shows a non-zero value for the TYPE item(Refer to the Table 5.29 for details) then the Cutter type is TOPREM or else it is STRAIGHT type or CURVED type. Figures 5.90 and 5.91 show the various terms associated with the modified cutter for Concave side and Convex side respectively.

If the CURVED type cutter is selected then a parameter called RHO (Special Analysis File Record#15, Item#12 for Concave side and Record#18, Item#12 for Convex Side) is added to the cutter menu. RHO is the spherical radius for the curved blade. If the Special Analysis File Record shows a non-zero value for the RHO item then the cutter type is CURVED or else it is STRAIGHT. A CURVED type cutter for concave and convex side tooth is shown in Figure 5.92 and Figure 5.93 respectively.

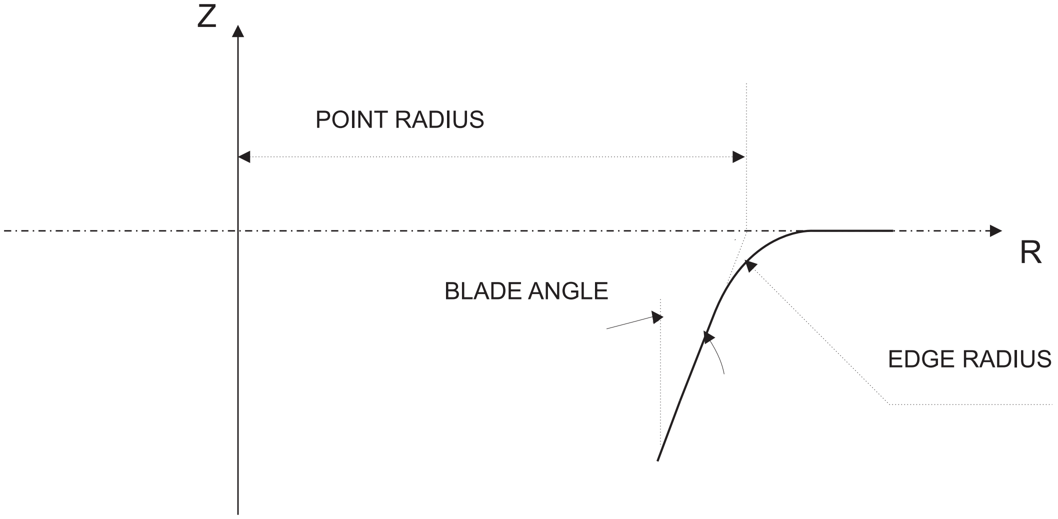

Z
POINT RADIUS
R
EDGE RADIUS
BLADE ANGLE

CUTTER FOR THE CONCAVE SIDE

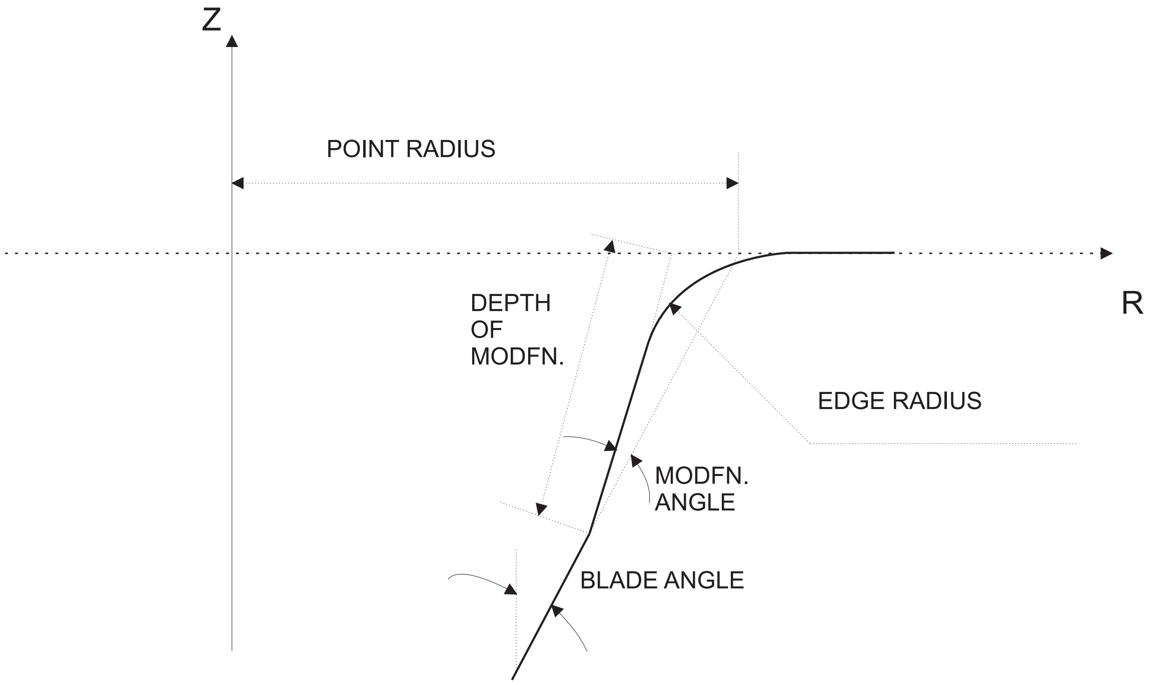

Z
POINT RADIUS
R
DEPTH. OF
MODFN
EDGE RADIUS
MODFN.
ANGLE
BLADE ANGLE

MODIFIED CUTTER FOR THE CONCAVE SIDE

Figure 5.90 Cutter description for Concave side (Old Cutter)


Z
POINT RADIUS
R
BLADE ANGLE
EDGE RADIUS

CUTTER FOR THE CONVEX SIDE


Z
POINT RADIUS
R
DEPTH
OF
MODFN.
EDGE RADIUS
MODFN.
ANGLE
BLADE ANGLE

MODIFIED CUTTER FOR THE CONVEX SIDE

Figure 5.91 Cutter description for Convex side (Old Cutter)

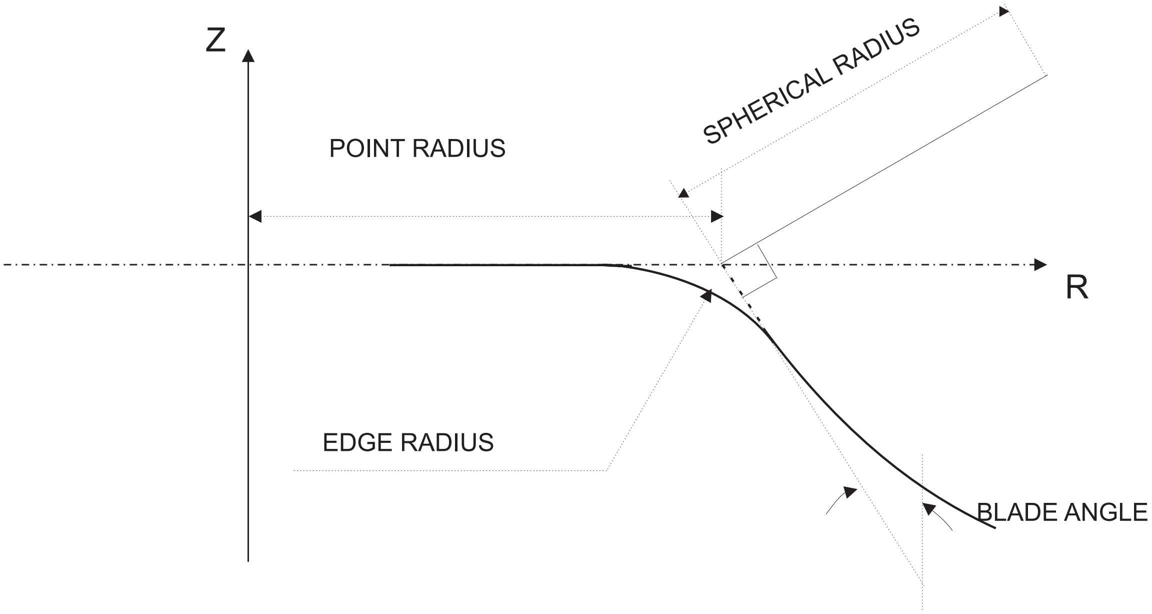

Z
SPHERICAL RADIUS
POINT RADIUS
R
EDGE RADIUS
BLADE ANGLE

Figure 5.92 Curved cutter description for Concave side (Old Cutter)

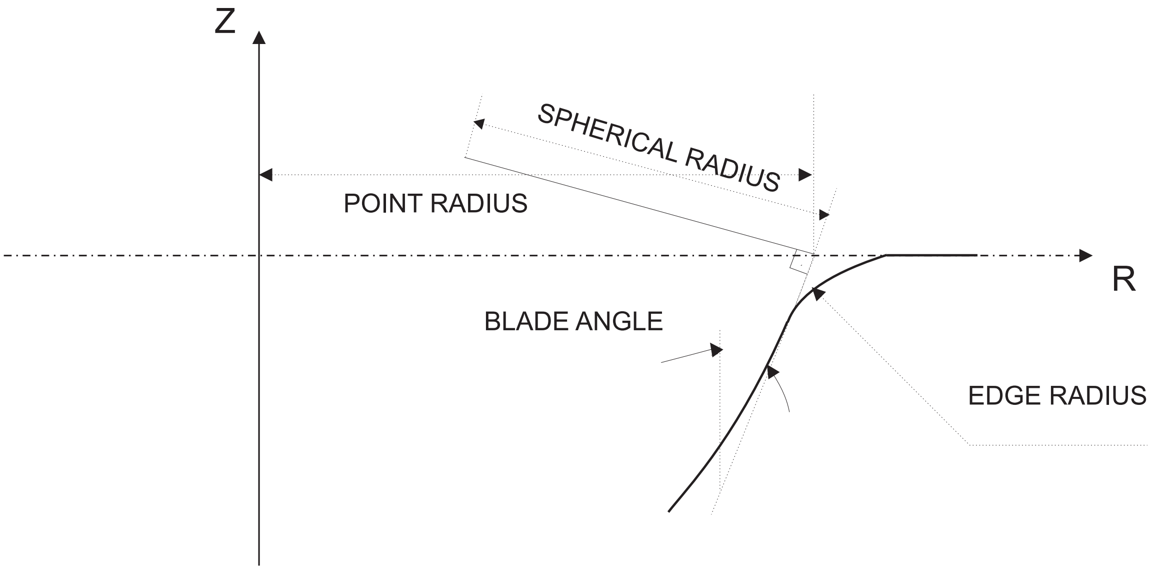

Z
SPHERICAL RADIUS
POINT RADIUS
R
BLADE ANGLE
EDGE RADIUS

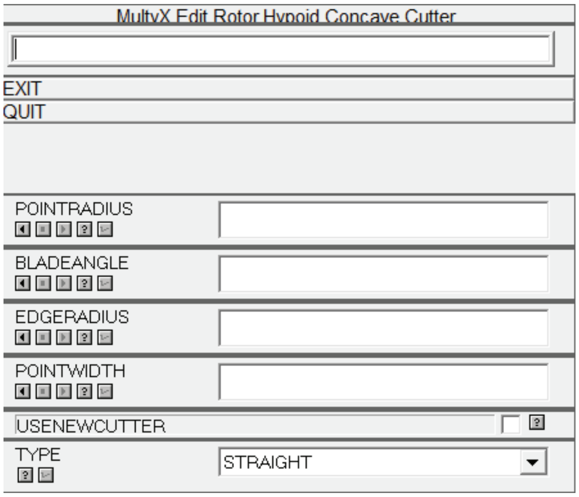
Figure 5.93 Curved cutter description for Convex side (Old Cutter)

Cutter Specifications for the generated type gear The CUTTER menu for the generated type gear is similar to that of the pinion cutter menu (Figure 5.80) except for the Special Analysis File details. Table 5.30 explains all the parameters associated with the Cutter menu for the generated type gear.

Table 5.30 Cutter specifications for concave and convex tooth side of a generated type gear

Item	Description	Special Analyis File Details
POINTRADIUS	Float, Radius of the cutter	Concave side-Record#25,Item#8 & Convex side-Record#21,Item#8
BLADEANGLE	Float, Cutter blade angle(Deg)	Concave side-Record#27,Item#4 & Convex side-Record#23,Item#4
EDGERADIUS	Float, Radius of the cutter edge(Tip radius)	Concave side-Record#26,Item#15 & Convex side-Record#22,Item#15
TYPE	Switch, Type of cutter(STRAIGHT/TOPREM)	Concave side-Record#27,Item#1 & Convex side-Record#23,Item#1

The special analysis file gives the blade angle(angle between the cutting edge of the cutter and the cutter axis of rotation) in radians. The user should convert that value in to degrees before entering it in to the BLADEANGLE menu. The default type of cutter is the STRAIGHT type, If the TOPREM type is used then two more parameters (TOPREMANGLE and TOPREMLENGTH) are added to the cutter menu. TOPREMANGLE (Special Analysis File Record#27, Item#1 for Concave and Record#23, Item#1 for Convex Side) is the angle that the modified part of the cutter makes with the unmodified part. When it is zero, modification has no effect. A positive angle implies that the material is being added to the tip of the cutter. The value of this angle given in the Special Analysis File is in radians. The user should convert it in to degrees before entering it in the TOPREMANGLE menu. TOPREMLENGTH(Record#27, Item#2 for Concave side and Record#23, Item#2 for Convex side) is the distance from the cutter point of the start of the modified part of the cutter. If the Special Analysis File Record shows a non-zero value for the TYPE item(Refer to the Table 5.30 for details) then the Cutter type is TOPREM or else it is STRAIGHT type or CURVED type. If the CURVED type of cutter is used then a parameter called RHO pops up in the cutter menu. RHO (Special Analysis File Record#25, Item#12 for Concave and Record#21, Item#12 for Convex Side) is the spherical radius for the curved blade. If this value is zero then the cutter type is STRAIGHT or else it is CURVED.



TYPE: STRAIGHT

Figure 5.94 Cutter specifications for the formate gear

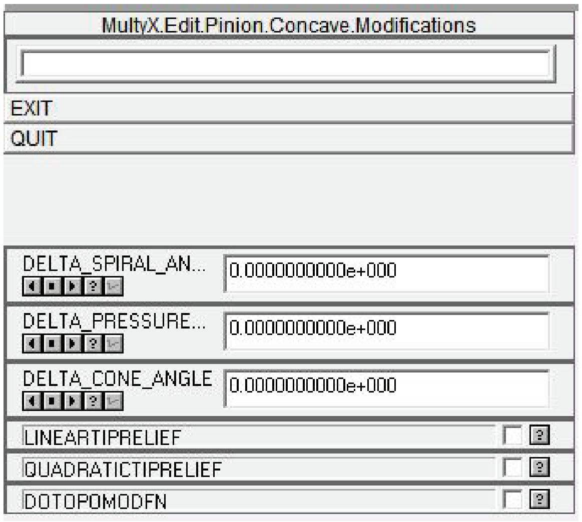
Table 5.31 Cutter specifications for concave and convex tooth side of a formate type gear

Item	Description	Special Analyis File Details
POINTRADIUS	Float, Radius of the cutter	Concave side-Record#25,Item#8 & Convex side-Record#21,Item#8
BLADEANGLE	Float, Cutter blade angle(Deg)	Concave side-Record#27,Item#4 & Convex side-Record#23,Item#4
EDGERADIUS	Float, Radius of the cutter edge(Tip radius)	Concave side-Record#26,Item#15 & Convex side-Record#22,Item#15
POINTWIDTH	Float, Difference between the point radii of the outside and inside blades of an alternate blade cutter	Concave side-Record#28,Item#10 & Convex side-Record#24,Item#10
TYPE	Switch, Type of cutter(STRAIGHT/TOPREM)	Concave side-Record#27,Item#1 & Convex side-Record#23,Item#1

Cutter Specifications for the formate type gear If you select the gear type as formate gear then the CUTTER command in the Concave/Convex menus leads to the menu shown in Figure 5.94. Table 5.31 explains all the terms associated with this menu.

5.7.1.3 Surface Modifications MODIFICATIONS command in Figure 5.76 leads to the Surface modification menu shown in Figure 5.95. The modifications for Spiral, Pressure and Cone angles all lead to increases in the their respective angles, shown in Figure 5.96. The sign convention for each of the angles is positive as shown in the figure. Note, the DELTA_CONE_ANGLE parameter is dependent upon the the DELTA_PRESSURE_ANGLE and DELTA_SPIRAL_ANGLE inputs, therefor a DELTA_CONE_ANGLE value should not be input if also entering values for the remaing two parameters. Table 5.32 provides a more detailed description of each of the 3 angle modifications.

The LINEARTIPRELIEF flag controls whether or not linear tip relief will be applied and expands the menu to Figure 5.97. Tip relief is specified in three locations and for each location the Magnitude, Tip Distance and Distance from the face cone axis must be specified. The QUADRATICTIPRELIEF flag controls whether or not quadratic tip relief will be applied and has similiar menu and inputs to linear tip relief. A graphical depiction of the inputs is shown in Figure 5.99.



DELTA_SPIRAL_AN... 0.0000000000e+000

DELTA_PRESSURE... 0.0000000000e+000

DELTA_CONE_ANGLE 0.0000000000e+000

LINEARTIPRELIEF ☐

QUADRATICTIPRELIEF ☐

DOTOPOMODFN ☐

Figure 5.95 Surface Modification menu

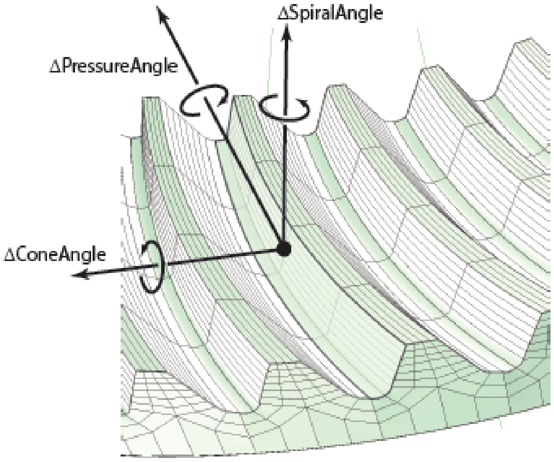


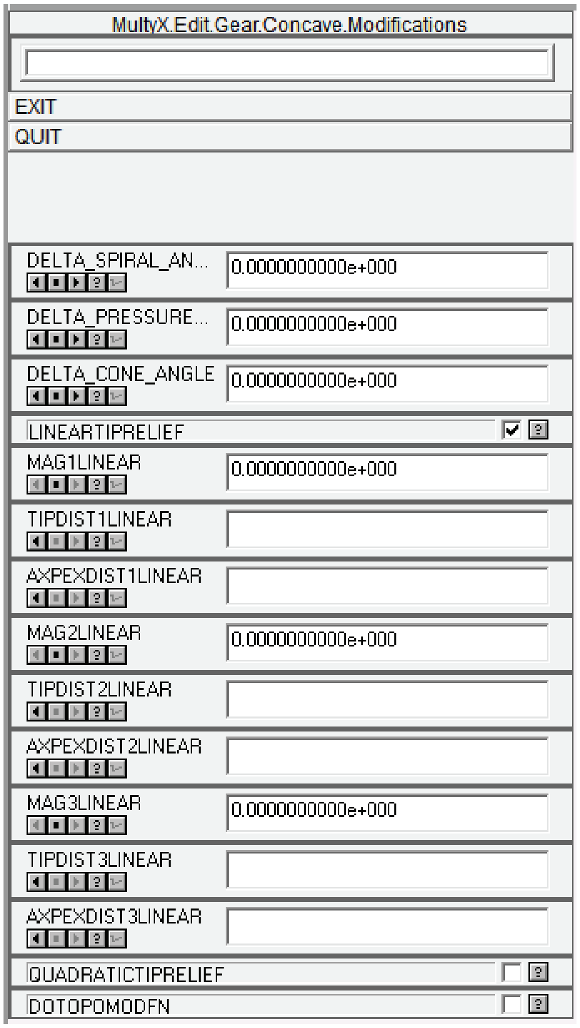
Figure 5.96 Angle Modifications

The DOTOPOMODFN flag controls whether or not surface modifications based on numerical data (such as from CMM) will be applied. If you check the DOTOPOMODFN box then the Surface Modifications menu applied on the Gear Concave side shown in Figure 5.98 becomes available. The Surface Modifications menu applied on the Convex side of the tooth is similar to that on the Concave side. The TOPOMODTYPE specifies which type of modification file is to be used. The data file name containing the surface modifications should be entered in the ZEISSFILE textbox. SCALEFACTOR allows for the data points within the modification file to by multiplied by this scale factor. If the file is in inches and your analysis is in mm, you can provide a scale factor of 25.4. The order of this polynomial in the profile direction is PROFORDER and that in the face width direction is FACEORDER.

The Surface Modifications menu for the gear tooth is similar to that of the pinion.

Table 5.32 Angle Modification Descriptions

Item	Description
DELTA_SPIRAL_ANGLE	Increase in spiral angle. This angle is in Degrees. Provide a non-zero value to this variable to indtroduce a surface modification which will increase the effective spiral angle.
DELTA_PRESSURE_ANGLE	Increase in pressure angle. This angle is in Degrees. Provide a non-zero value to this variable to indtroduce a surface modification which will increase the effective pressure angle.
DELTA_CONE_ANGLE	Increase in cone angle. This angle is in Degrees. Provide a non-zero value to this variable to indtroduce a surface modification which will increase the effective cone angle.


MultyX.Edit.Gear.Concave.Modifications

EXIT

QUIT

DELTA_SPIRAL_AN... 0.0000000000e+000

DELTA_PRESSURE... 0.0000000000e+000

DELTA_CONE_ANGLE 0.0000000000e+000

LINEARTIPRELIEF ☑

MAG1LINEAR 0.0000000000e+000

TIPDIST1LINEAR

AXPEXDIST1LINEAR

MAG2LINEAR 0.0000000000e+000

TIPDIST2LINEAR

AXPEXDIST2LINEAR

MAG3LINEAR 0.0000000000e+000

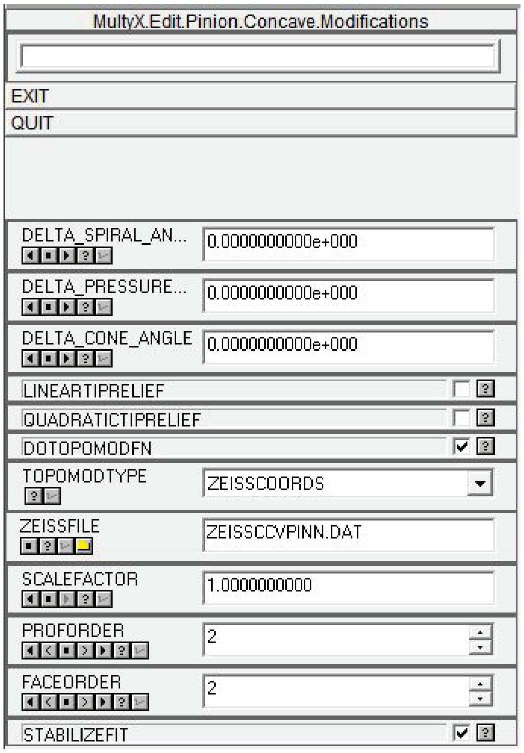
TIPDIST3LINEAR

AXPEXDIST3LINEAR

QUADRATICTIPRELIEF ☐

DOTOPOMODFN ☐

Figure 5.97 Linear Tip Relief menu


MultyX.Edit.Pinion.Concave.Modifications
EXIT
QUIT

DELTA_SPIRAL_AN... 0.0000000000e+000
DELTA_PRESSURE... 0.0000000000e+000
DELTA_CONE_ANGLE 0.0000000000e+000
LINEARTIPRELIEF ☐
QUADRATICTIPRELIEF ☐
DOTOPOMODFN ☑
TOPOMODTYPE ZEISSCOORDS
ZEISSFILE ZEISSCCVPINN.DAT
SCALEFACTOR 1.0000000000
PROFORDER 2
FACEORDER 2
STABILIZEFIT ☑

Figure 5.98 Surface Modification applied on the gear concave side

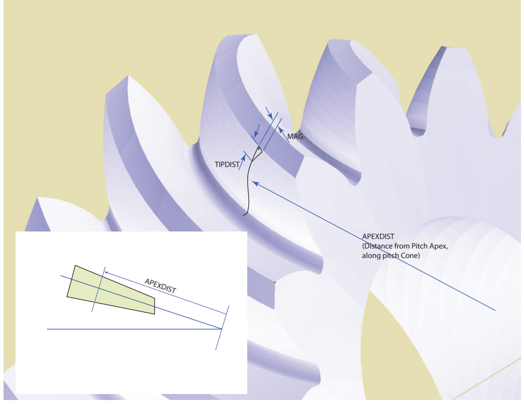
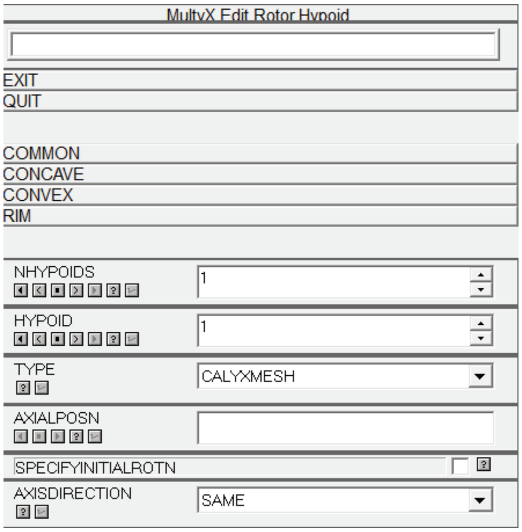

MAG
TIPDIST
APEXDIST
(Distance from Pitch Apex,
along pitch Cone)
APEXDIST

Figure 5.99 Hypoid tip relief input parameters.



NHYPOIDS 1

HYPOID 1

TYPE CALYXMESH

AXIALPOSN

AXISDIRECTION SAME

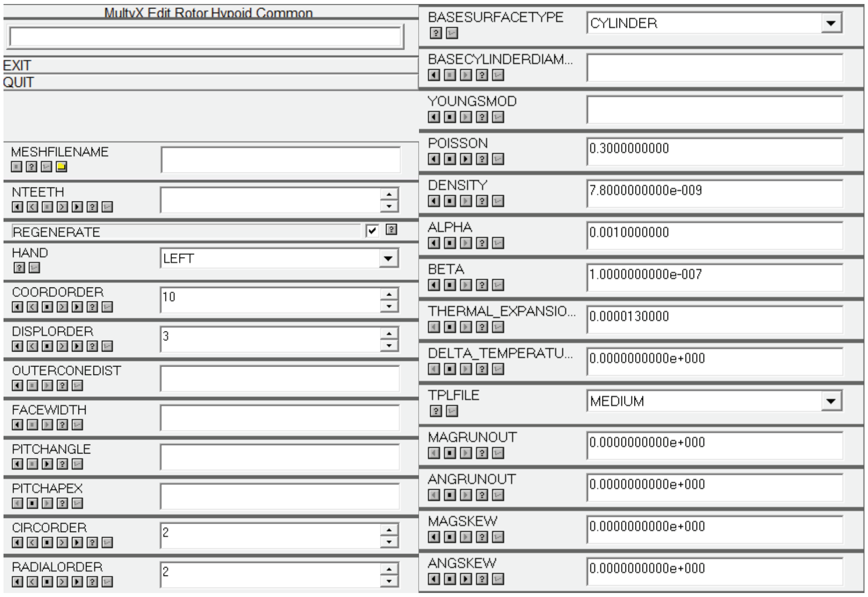
Figure 5.100 Hypoid menu for CALYXMESH tooth type.

5.7.2 CALYXMESH Tooth Type

Selecting the CALYXMESH tooth TYPE within the HYPOID menu allows us to import a calyx mesh file (`.msh`) generated by *HypoidFaceMilled* or *HypoidFaceHobbed*. Figure 5.100 shows the HYPOID menu with this tooth type selected. The HYPOID menu is identical to the HYPOID menu for the FACEMILLED_PINION or FACEHOBBED_PINION, with the exception of the SPAFILE menu being absent in the CALYXMESH case.

The COMMON menu is shown in Figure 5.101. All of the COMMON menu parameters shown are also present in the COMMON menu for the FACEHOBBED and FACEMILLED types, with the exception of the MESHFILENAME input and REGENERATE flag. MESHFILENAME is simply the filename of the `.msh` file to be imported. When the REGENERATE flag is turned ON, the mesh will be regenerated.This allows you to have different material properties and base cone definition than that used in the originalpinion mesh file. If it is turned OFF, then the originalmesh will be used directly.

The CONCAVE and CONVEX menus do not contain the MACHINE and CUTTER submenus, but are otherwise identical to those of the FACEMILLED and FACEHOBBED types. The menues are shown in Figures 5.102 and 5.103.


MultyX Edit Rotor Hypoid Common
EXIT
QUIT

MESHFILENAME
NTEETH
REGENERATE ☑
HAND LEFT
COORDORDER 10
DISPLORDER 3
OUTERCONEDIST
FACEWIDTH
PITCHANGLE
PITCHAPEX
CIRCORDER 2
RADIALORDER 2
BASESURFACETYPE CYLINDER
BASECYLINDERDIAM...
YOUNGSMOD
POISSON 0.3000000000
DENSITY 7.8000000000e-009
ALPHA 0.0010000000
BETA 1.0000000000e-007
THERMAL_EXPANSIO... 0.0000130000
DELTA_TEMPERATU... 0.0000000000e+000
TPLFILE MEDIUM
MAGRUNOUT 0.0000000000e+000
ANGRUNOUT 0.0000000000e+000
MAGSKEW 0.0000000000e+000
ANGSKEW 0.0000000000e+000

Figure 5.101 Common menu for CALYXMESH tooth type.

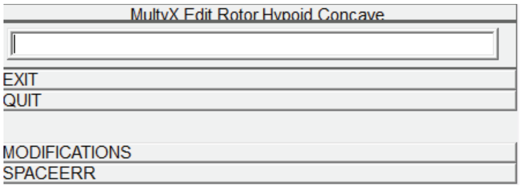

MultyX Edit Rotor Hypoid Concave
EXIT
QUIT
MODIFICATIONS
SPACEERR

Figure 5.102 Concave menu for CALYXMESH tooth type.

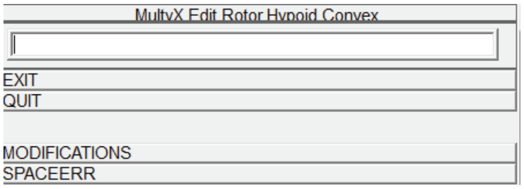
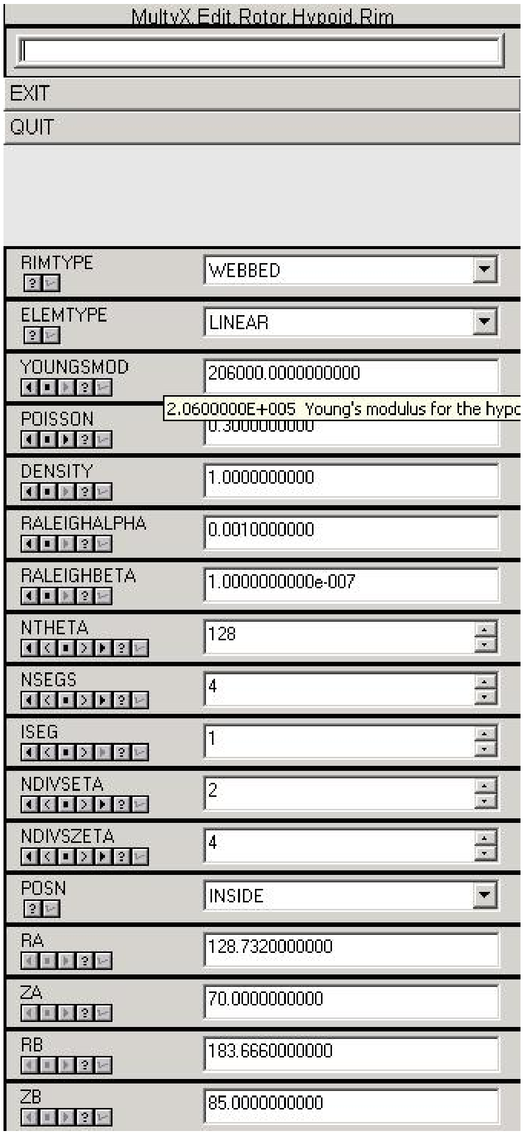

MultyX Edit Rotor Hypoid Convex
EXIT
QUIT
MODIFICATIONS
SPACEERR

Figure 5.103 Convex menu for CALYXMESH tooth type.



RIMTYPE	WEBBED
ELEMTYPE	LINEAR
YOUNGSMOD	206000.0000000000
POISSON	0.3000000000
DENSITY	1.0000000000
RALEIGHALPHA	0.0010000000
RALEIGHBETA	1.0000000000e-007
NTHETA	128
NSEGS	4
ISEG	1
NDIVSETA	2
NDIVSZETA	4
POSN	INSIDE
RA	128.7320000000
ZA	70.0000000000
RB	183.6660000000
ZB	85.0000000000

2.0600000E+005 Young's modulus for the hyp

Figure 5.104 The Hypoid gear RIM menu.

5.7.3 The Hypoid gear rim

Thr RIM command in the HYPOID menu (Figure 5.66) leads to the RIM menu shown in Figure 5.104. This is very similar to the bevel rim menu.

The RIMTYPE item can be either NONE or WEBBED. If it is set to NONE, then the base of the tooth finite element model will be used as the race surface.

The WEBBED rim is specified by sequence of segments as shown for the bevel gear in Figure 5.60. The first segment is closest to the tooth, and the last segment is the farthest. Each segment ‘i’ has two endpoints. Depending on the POSITION of the rim segment, there are four different ways in which it attaches to the previous segemt (Figures 5.36 to 5.39) Table 5.33 shows the meaning of the parameters in this menu.

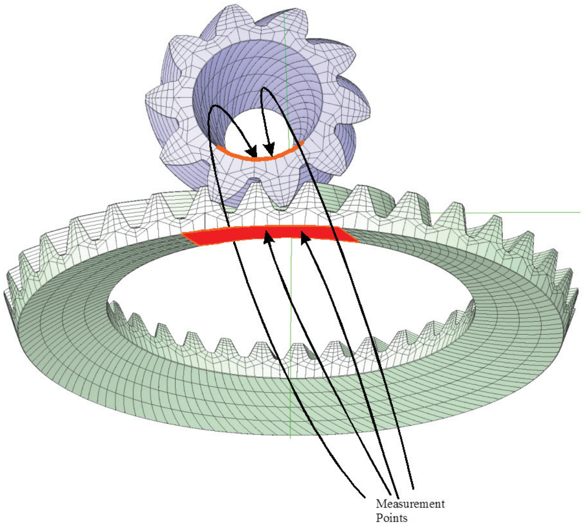
5.7.4 Hypoid Assembly Errors

Table 5.33 The hypoid gear rim parameters

Item	Description
RIMTYPE	Switch, Options are NONE and WEBBED
ELEMTYPE	Switch, Type of finite element. Available options are LINEAR, QUADRATIC and CUBIC
YOUNGSMOD	Float, Youngs modulus for the hypoid gear
POISSON	Float, Poisson's ratio for the hypoid gear
DENSITY	Float, Density of the hypoid gear
RALEIGHALPHA	Float, Damping constant alpha for the hypoid gear
RALEIGHBETA	Float, Damping constant beta for the hypoid gear
NTHETA	Integer, The is the number of finite elements used in the circular direction of the rim
NSEGS	Integer, Number of segments used to define the rim
ISEG	Integer, Segment number for which data is being displayed
NDIVSETA	Integer, Vector indexed by ISEG, Number of elements along the η direction of the segment.
NDIVSZETA	Integer, Vector indexed by ISEG, Number of elements along the ζ direction of the segment.
POSN	Switch, Vector indexed by SEGMENT, Relative position of the rim segment.
RA	Float, Vector indexed by ISEG, Radial coordinate at side A.
ZA	Float, Vector indexed by ISEG, Z coordinate at side A.
RB	Float, Vector indexed by ISEG, Radial coordinate at side B.
ZB	Float, Vector indexed by ISEG, Z coordinate at side B.

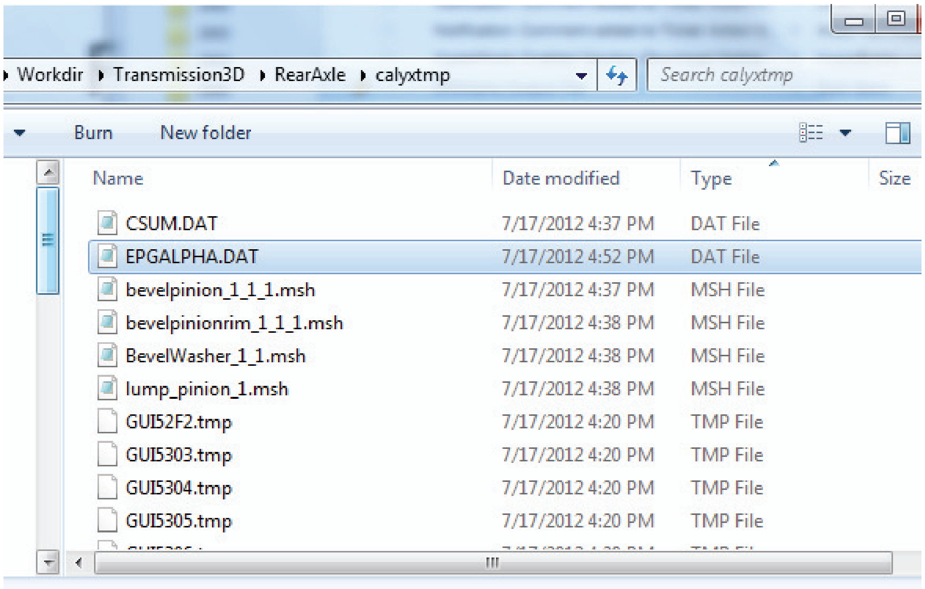
The hypoid assembly errors are available as an output from the model analysis. Figure 5.105 shows the methodology used in determining the magnitude of the assembly errors E, P, G, and α. The output file `EPGALPHA.DAT` is automatically created in the `calyxtmp` subfolder of the working directory as shown in Figure 5.106. The file format of the assembly error file is shown in Figure 5.107. Figures 5.108 through 5.111 show the definition and sign convention of the E, P, G and α assembly errors for both left-hand and right-hand gears.

5.8 Modeling the Carrier



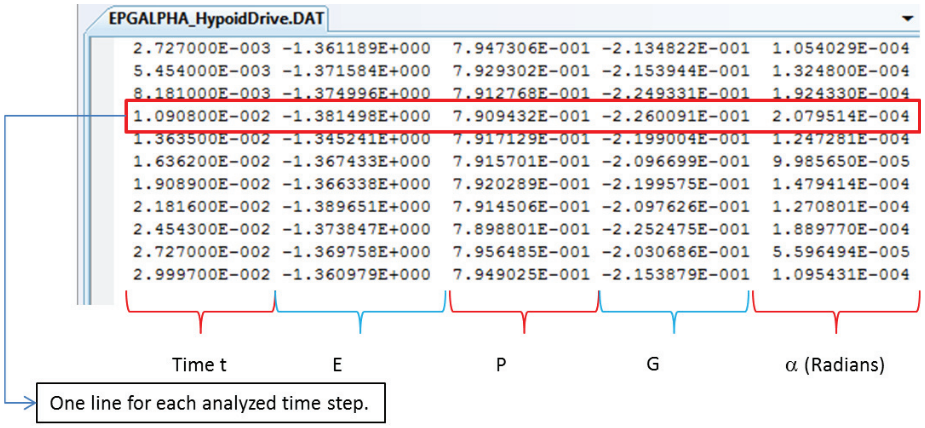
1. The 3D deflection is calculated at all nodes at the base of teeth that have non-zero tooth load.
2. Separately for the pinion and gear, we calculate the 6 components of rigid body motions that is the best fit (in least squares sense) to the measured deflections.
3. These 12 rigid body components for the two bodies are vectorially converted to 6 **relative** motion components.
4. There are 2 components that do not contribute to gear deflection: rotation of the pinion about its own axis and rotation of the gear about its own axis.
5. We project the 6 components to the 4 useful deflection components. E,P,G,α
6. These E,P,G,α are ready for use in simpler analysis (two gear loaded or unloaded TCA)

Figure 5.105 Calculation of E, P, G, α values.



Name	Date modified	Type	Size
CSUM.DAT	7/17/2012 4:37 PM	DAT File	
EPGALPHA.DAT	7/17/2012 4:52 PM	DAT File	
bevelpinion_1_1_1.msh	7/17/2012 4:37 PM	MSH File	
bevelpinionrim_1_1_1.msh	7/17/2012 4:38 PM	MSH File	
BevelWasher_1_1.msh	7/17/2012 4:38 PM	MSH File	
lump_pinion_1.msh	7/17/2012 4:38 PM	MSH File	
GUI52F2.tmp	7/17/2012 4:20 PM	TMP File	
GUI5303.tmp	7/17/2012 4:20 PM	TMP File	
GUI5304.tmp	7/17/2012 4:20 PM	TMP File	
GUI5305.tmp	7/17/2012 4:20 PM	TMP File	

Figure 5.106 Locating the assembly error output file.


EPGALPHA_HypoidDrive.DAT
Time t
E
P
G
α (Radians)
One line for each analyzed time step.

```
2.727000E-003 -1.361189E+000  7.947306E-001 -2.134822E-001  1.054029E-004
5.454000E-003 -1.371584E+000  7.929302E-001 -2.153944E-001  1.324800E-004
8.181000E-003 -1.374996E+000  7.912768E-001 -2.249331E-001  1.924330E-004
1.090800E-002 -1.381498E+000  7.909432E-001 -2.260091E-001  2.079514E-004
1.363500E-002 -1.345241E+000  7.917129E-001 -2.199004E-001  1.247281E-004
1.636200E-002 -1.367433E+000  7.915701E-001 -2.096699E-001  9.985650E-005
1.908900E-002 -1.366338E+000  7.920289E-001 -2.199575E-001  1.479414E-004
2.181600E-002 -1.389651E+000  7.914506E-001 -2.097626E-001  1.270801E-004
2.454300E-002 -1.373847E+000  7.898801E-001 -2.252475E-001  1.889770E-004
2.727000E-002 -1.369758E+000  7.956485E-001 -2.030686E-001  5.596494E-005
2.999700E-002 -1.360979E+000  7.949025E-001 -2.153879E-001  1.095431E-004
```

Figure 5.107 Format of the assembly error output file.

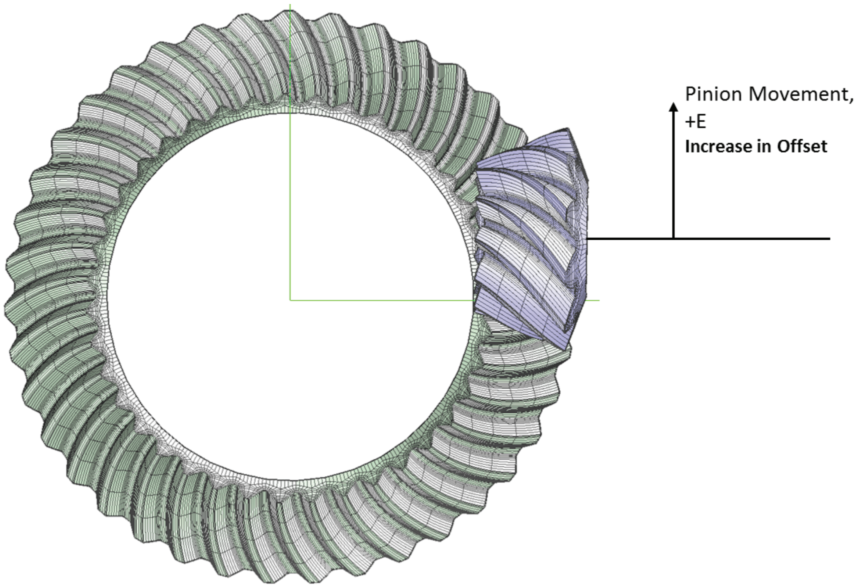

Pinion Movement,
+E
Increase in Offset

Figure 5.108 Left-handed gear sign convention for E assembly error parameter.

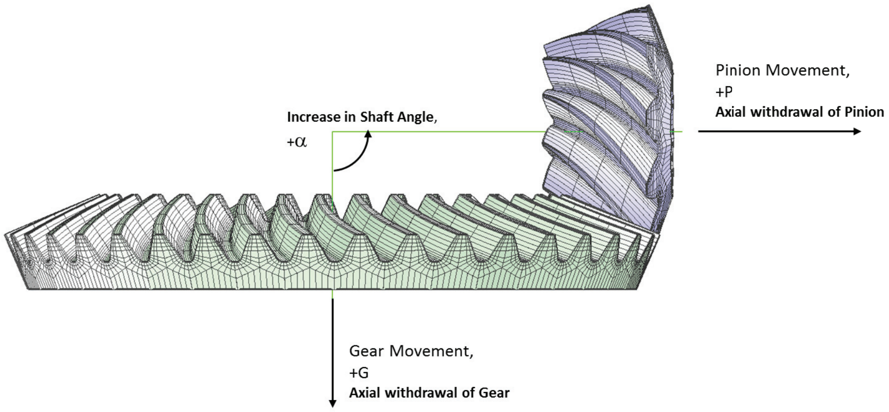

Pinion Movement,
+P
Axial withdrawal of Pinion
Increase in Shaft Angle,
+α
Gear Movement,
+G
Axial withdrawal of Gear

Figure 5.109 Left-handed gear sign convention for P, G, and α assembly error parameters.

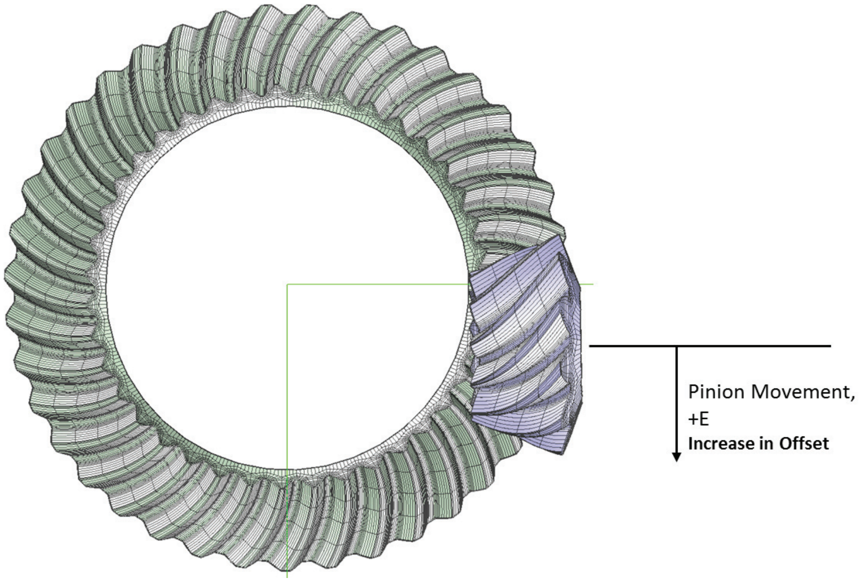

Pinion Movement,
+E
Increase in Offset

Figure 5.110 Right-handed gear sign convention for E assembly error parameter.

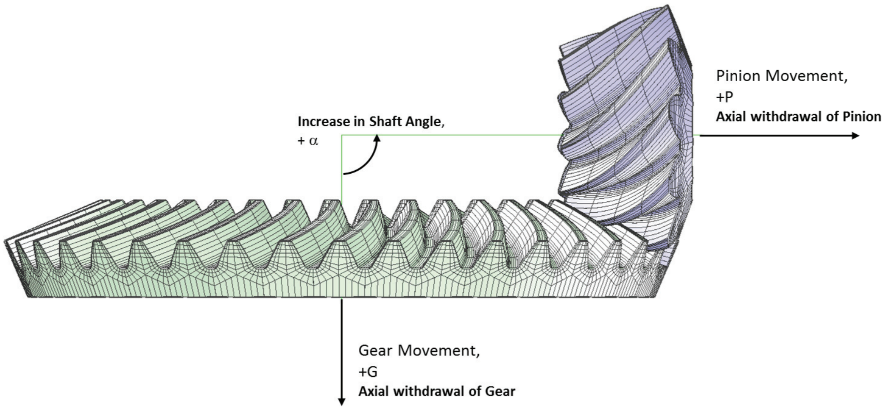
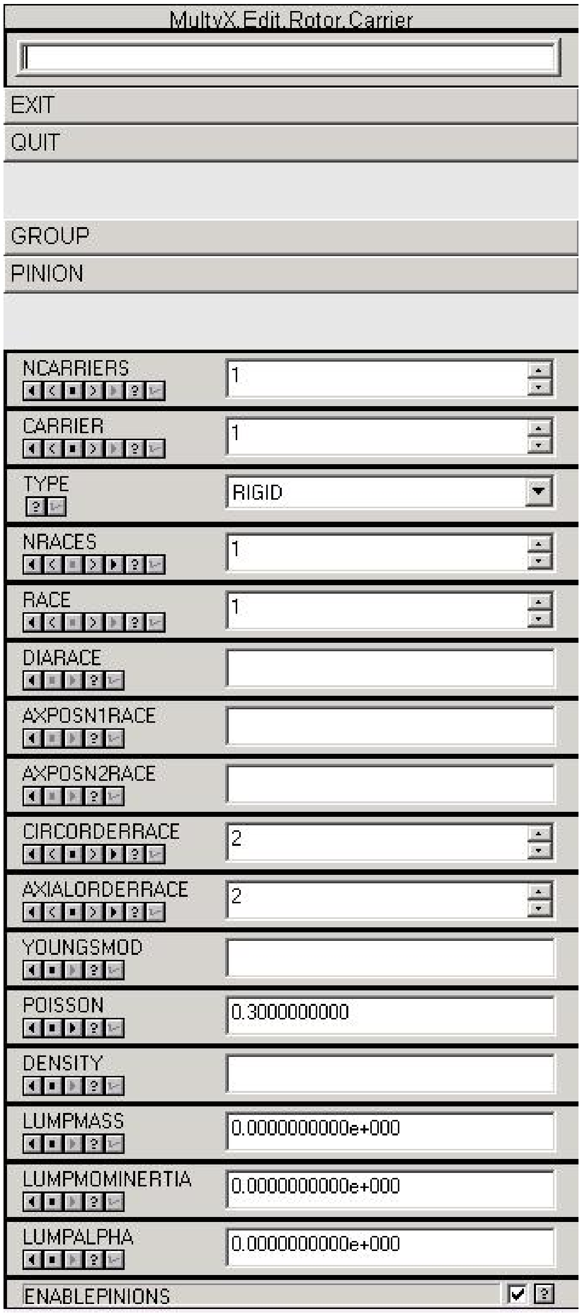

Pinion Movement,
+P
Axial withdrawal of Pinion
Increase in Shaft Angle,
+ α
Gear Movement,
+G
Axial withdrawal of Gear

Figure 5.111 Right-handed gear sign convention for P, G, and α assembly error parameters.

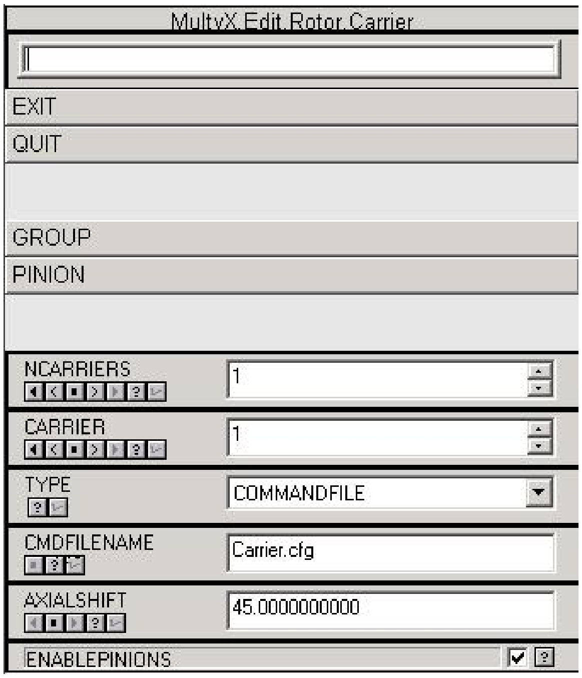
The CARRIER command in the rotor menu of Figure 5.4 leads to the carrier menu shown in Figure 5.112. A carrier is a structure meant for carrying pinions in a planetary system or bevel differential system. The carrier attaches to other components in the rotor through ’Shaft Races’. It connects to pinions trough ’Pinion Races’.

Each rotor can carry any number of such carriers. The number of carriers is specified in the NCARRIERS item. The CARRIER item selects the particular carrier for whic the remaining data is displayed. The TYPE item can be set to either RIGID or COMMANDFILE. The RIGID type of carrier assumes a rigid connection between the pinion races and the shaft races of the carrier. Figure 5.112 shows the CARRIER menu when TYPE is RIGID, and Figure 5.113 shows it when TYPE is COMMANDFILE.


MultyX.Edit.Rotor.Carrier
EXIT
QUIT
GROUP
PINION

NCARRIERS	1
CARRIER	1
TYPE	RIGID
NRACES	1
RACE	1
DIARACE	
AXPOSN1RACE	
AXPOSN2RACE	
CIRCORDERRACE	2
AXIALORDERRACE	2
YOUNGSMOD	
POISSON	0.3000000000
DENSITY	
LUMPMASS	0.0000000000e+000
LUMPMOMINERTIA	0.0000000000e+000
LUMPALPHA	0.0000000000e+000
ENABLEPINIONS	☑

Figure 5.112 The carrier menu shown when TYPE is RIGID.


MultyX.Edit.Rotor.Carrier
EXIT
QUIT
GROUP
PINION

NCARRIERS 1
CARRIER 1
TYPE COMMANDFILE
CMDFILENAME Carrier.cfg
AXIALSHIFT 45.0000000000
ENABLEPINIONS ☑

Figure 5.113 The carrier menu as seen when TYPE is set to COMMANDFILE.

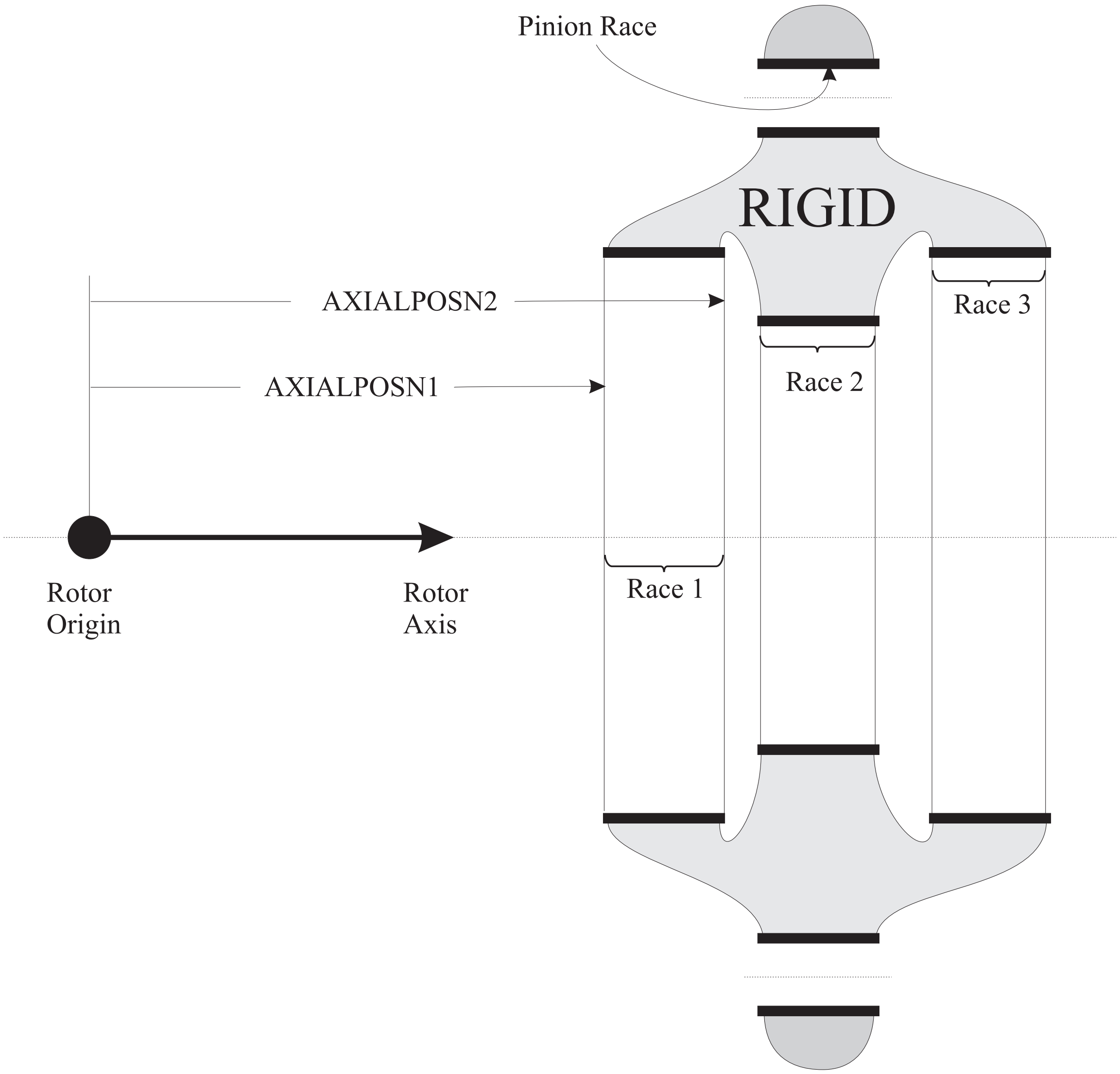


Figure 5.114 A rigid carrier and its races.

5.8.1 Rigid Carrier

Figure 5.114 shows a schematic of a rigid carrier. It has a number of cylindrical 'race' surfaces where it connects with the other omponents in the rotor. The number of these races used is entered in NRACE. The RACE item selects the race for which the remaining data is displayed.

The axial position of the race is specified by AXIALPOSN1 and AXIALPOSN2. The diameter is specified by DIARACE. Each race has a small elastic annular region for connecting the rigid carrier to the flexible shaft race. The material properties YOUNGSMOD, POISSON, DENSITY, RALEIGHALPHA and RALEIGHBETA are used there. The order of Fourier series used for displacement interpolation at the interface between the carrier race and the shaft segment model is given by CIRCORDERRACE parameter and the order of the polynomial series used for displacement interpolation in the axial direction is given by AXIALORDERRACE parameter. Table 5.34 gives a brief summary of the various terms used in the CARRIER menu.

LUMPMASS and LUMPMOMINERTIA are the lumped mass and polar moment of inertia of the carrier. Viscous damping proportional to the mass cann be introduced through the LUMPALPHA term.

Table 5.34 The Carrier menu

Item	Description
NCARRIERS	Integer, Number of carriers in the rotor
CARRIER	Integer, Carrier number
TYPE	Switch, Type of model to be used for the carrier. It may be RIGID or COMMANDFILE
NRACES	Integer, Number of shaft races on the carrier (Active if TYPE=RIGID)
RACE	Integer, Carrier race (Active if TYPE=RIGID)
DIARACE	Float, Diameter of the race (Active if TYPE=RIGID)
AXIALPOSN1RACE	Float, Axial position of the race (Active if TYPE=RIGID)
AXIALPOSN2RACE	Float, Axial position of the race (Active if TYPE=RIGID)
CIRCORDERRACE	Integer, Fourier series order in the circular direction (Active if TYPE=RIGID)
AXIALORDERRACE	Integer, Polynomial order in the axial direction (Active if TYPE=RIGID)
YOUNGSMOD	Float, Young’s modulus of the flexible region where the rigid carrier connects the flexible shafts (Active if TYPE=RIGID)
POISSON	Float, Poisson’s ratio of the flexible region where the rigid carrier connects the flexible shafts (Active if TYPE=RIGID)
DENSITY	Float, Density of the flexible region where the rigid carrier connects the flexible shafts (Active if TYPE=RIGID)
LUMPMASS	Float, Lumped mass at the carrier center (Active if TYPE=RIGID)
LUMPMOMINERTIA	Float, Lumped polar moment of inertia J_z at the center (Active if TYPE=RIGID)
LUMPALPHA	Float, Damping constant alpha for the lumped mass (Active if TYPE=RIGID)
CMDFILENAME	String, the name of the command file that contains a definition of the carrier.(Active if TYPE=COMMANDFILE)
AXIALSHIFT	Float, The axial shift to be applied to the model defined in the command file.(Active if TYPE=COMMANDFILE)
ENABLEPINIONS	Boolean. Whether or not the carrier has pinions

The ENABLEPINIONS flag, when turned on, allows the carrier to have pinions.

5.8.2 Flexible Carrier created outside *Transmission3D*: The COMMANDFILE Option

This option is OUTDATED and NOT RECOMMENDED. A description of the process for using this option however is provided below for user’s who may still need it. Refer to the following section for details on the recommended method for importing an externally created FE carrier model.

When a detailed model of the Carrier is created outside of *Transmission3D*, it can be imported by specifying the COMMANDFILE type.

The carrier shown in Figure 5.115 was created as a NASTRAN bulk data file, and then converted to a *Calyx* command file using *cvtbdf* utility. This carrier contains several races and a set of straight bevel pinions.

Figure 5.113 shows the CARRIER menu as it appears when using a COMMANDFILE type of carrier. CMDFILENAME is the name of the *Calyx* command file that contains all the information regarding the

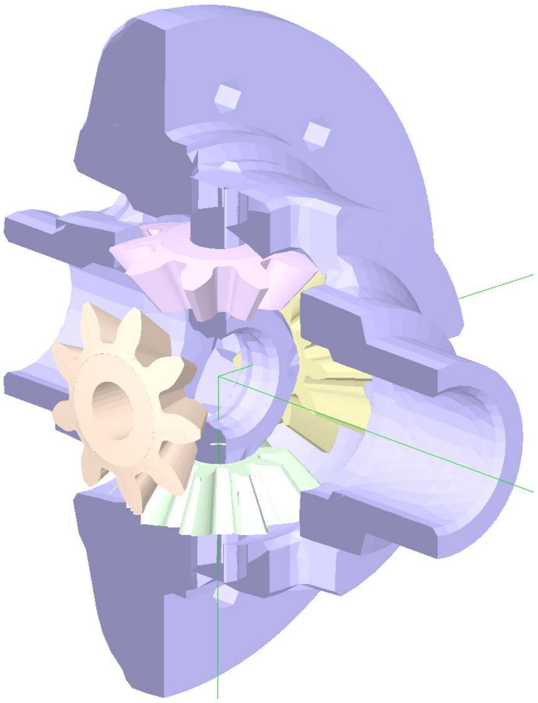
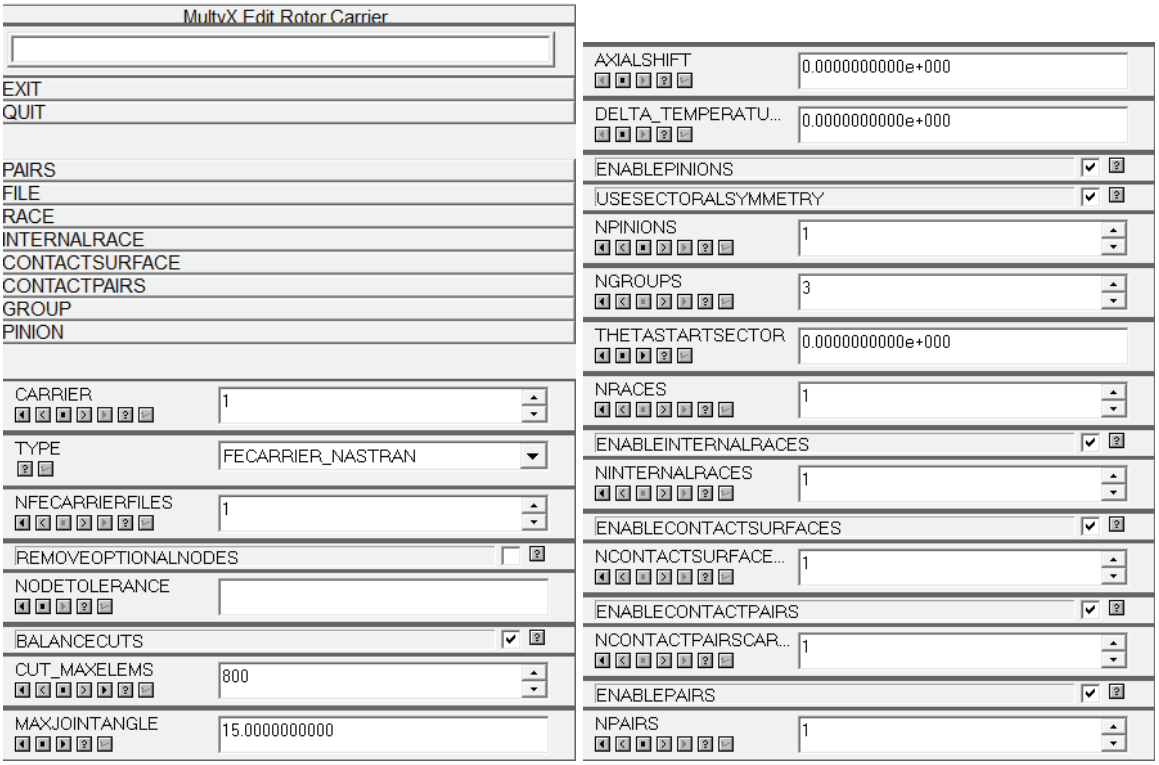


Figure 5.115 A carrier created outside of *Transmission3D* and imported using the CMDFILETYPE.

carrier. A further shift in the axial direction can be applied to the entire carrier through the AXIALSHIFT item.

The ENABLEPINIONS flag should be turned on if the carrier has pinions.



CARRIER 1
TYPE FECARRIER_NASTRAN
NFECARRIERFILES 1
REMOVEOPTIONALNODES ☐
NODETOLERANCE
BALANCECUTS ☑
CUT_MAXELEMS 800
MAXJOINTANGLE 15.0000000000
AXIALSHIFT 0.0000000000e+000
DELTA_TEMPERATU... 0.0000000000e+000
ENABLEPINIONS ☑
USESECTORALSYMMETRY ☑
NPINIONS 1
NGROUPS 3
THETASTARTSECTOR 0.0000000000e+000
NRACES 1
ENABLEINTERNALRACES ☑
NINTERNALRACES 1
ENABLECONTACTSURFACES ☑
NCONTACTSURFACE... 1
ENABLECONTACTPAIRS ☑
NCONTACTPAIRSCAR... 1
ENABLEPAIRS ☑
NPAIRS 1

Figure 5.116 The carrier menu inputs when the FECARRIER_NASTRAN type is selected.

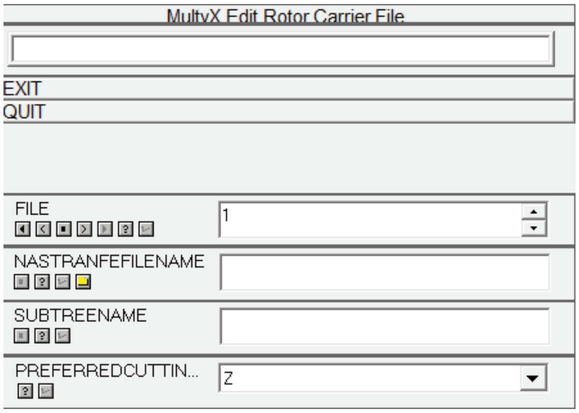
5.8.3 Flexible Carrier created outside *Transmission3D*: The FECARRIER Option

The recommended method for importing a carrier model created using an external FEA software package is the FECARRIER carrier TYPE. There are two choices when using this method: FECARRIER_NASTRAN and FECARRIER_ABAQUS. The two methods differ only in the file extensions allowed. The acceptable file extentions for each type are the Nastran (`.bdf`) and Abaqus (`.inp`) extensions.

The CARRIER menu for the FECARRIER type is shown in Figure 5.116 and a description of each of the menu items is provided in Table 5.35. The carrier submenus specific to the FECARRIER type are the FILE, PAIRS, RACE, INTERNALRACE, CONTACTSURFACE, and CONTACTPAIRS menus.

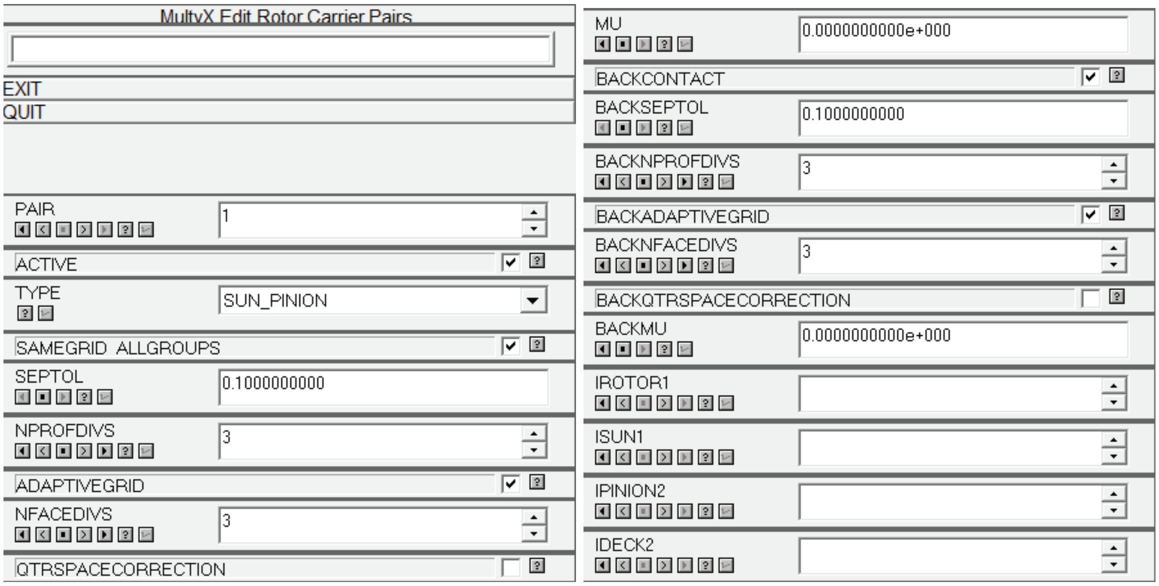
Table 5.35 The carrier menu inputs for the FECARRIER type.

Item	Description
CARRIER	Integer, Carrier number
TYPE	Switch, Type of model to be used for the carrier
NFECARRIERFILES	Integer, The number of FE files to import for the carrier
REMOVEOPTIONALNODES	Boolean, Removes mid nodes of quadratic elements
NODETOLERANCE	Float, Sets the tolerance for compatible nodes on race surfaces
BALANCECUTS	Boolean, Balances the substructure heirarchy so that each terminal branch has roughly the same number of elements
CUT_MAXELEMS	Integer, Sets the maximum number of elements for any single substructure
MAXJOINTANGLE	Float, Maximum angle for smoothing sharp edges. Any edges angles less than this angle will be smoothed
AXIALSHIFT	Float, The distance along the rotor axis to shift the carrier
DELTA_TEMPERATURE	Float, The change in temperature to be applied to the carrier for thermal analysis
ENABLEPINIONS	Boolean, Enables pinions on the carrier
USESECTORALSYMMETRY	Boolean, Enables the user to utilize an axialsymmetric FE carrier model by importing a single sector
NPINIONS	Integer, The number of pinions
NGROUPS	Integer, The number of groups. This is also the number of sectors if USESECTORALSYMMETRY is enabled
THETASTARTSECTOR	Float, The angle where the first surface of the sector is located following the RH rule about the rotational axis
NRACES	Integer, The number of axialsymmetric races to include
ENABLEINTERNALRACES	Boolean, Enables the ability to include races not axially symmetric
NINTERNALRACES	Integer, The number of non-axialsymmetric races to model
ENABLECONTACTSURFACES	Boolean, The axial shift to be applied to the model defined in the command file.(Active if TYPE=COMMANDFILE)
NCONTACTSURFACES	Integer, The number of contact surface pairs, not including gear pairs
ENABLEPAIRS	Boolean, Whether or not the carrier has pinions
NPAIRS	Integer, The number of gear contact pairs



FILE 1
NASTRANFEFILENAME
SUBTREENAME
PREFERREDCUTTIN... Z

Figure 5.117 The file submenu of the FE carrier menu.



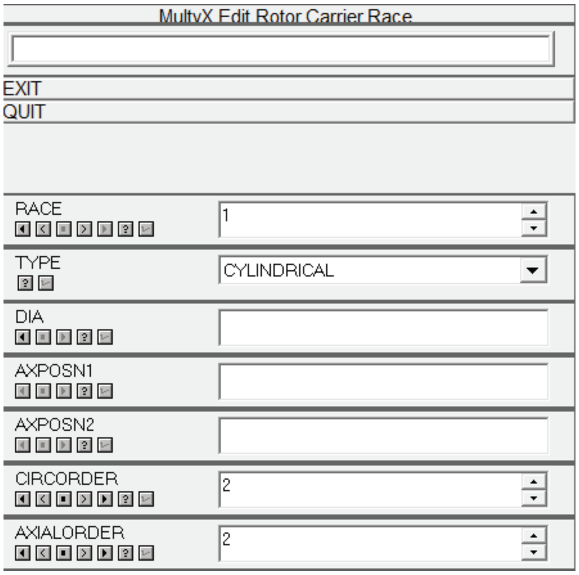
PAIR 1
ACTIVE ☑
TYPE SUN_PINION
SAMEGRID ALLGROUPS ☑
SEPTOL 0.1000000000
NPROFDIVS 3
ADAPTIVEGRID ☑
NFACEDIVS 3
QTRSPACECORRECTION ☐
MU 0.0000000000e+000
BACKCONTACT ☑
BACKSEPTOL 0.1000000000
BACKNPROFDIVS 3
BACKADAPTIVEGRID ☑
BACKNFACEDIVS 3
BACKQTRSPACECORRECTION ☐
BACKMU 0.0000000000e+000
IROTOR1
ISUN1
IPINION2
IDECK2

Figure 5.118 The gear pairs submenu of the FE carrier menu.

5.8.3.1 The File Menu The FILE menu, shown in Figure 5.117, is where the FE model file information is entered. The FILENAME is the filename of the FE file with the appropriate file extension for the selected type. SUBTREENAME sets the name of the FE mesh file component to be used for naming mesh files and within the model tree in iGlass. The preferred cutting direction sets the axis to use to break up the component mesh for importing. The most efficient axis to select is always the axis of symmetry. The FILE field sets the file index. If multiple housing files are being imported, changing the FILE number shows the menu inputs for the specified file number.

5.8.3.2 The Pairs Menu The PAIRS menu (Figure 5.118) is active only when the ENABLEPAIRS box is selected. The menu allows the user to model the carrier gear pair contact inputs differently for each pinion group by unselecting the SAMEGRID ALLGROUPS check box. If the contact grids will be identical for all groups, the pair information can be entered into either the EDIT>PAIRS menu or this menu with the SAMEGRID ALLGROUPS box selected. Refer to the ’Pairs’ section for a description of each input.

5.8.3.3 The RACE Menu The RACE submenu appears automatically if either FECARRIER_NASTRAN or FECARRIER_ABAQUS is selected for the carrier type. The race menu is used to input the race informa-



MultyX Edit Rotor Carrier Race

EXIT

QUIT

RACE: 1

TYPE: CYLINDRICAL

DIA:

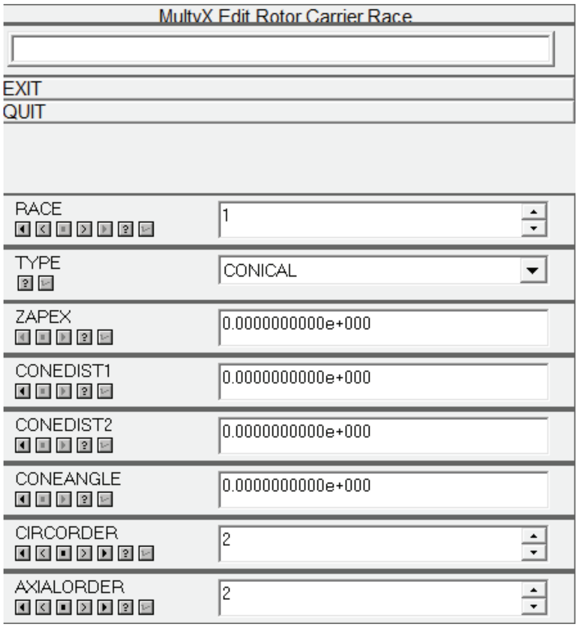
AXPOSN1:

AXPOSN2:

CIRCORDER: 2

AXIALORDER: 2

Figure 5.119 The race submenu for the cylindrical race type.



MultyX Edit Rotor Carrier Race

EXIT

QUIT

RACE: 1

TYPE: CONICAL

ZAPEX: 0.0000000000e+000

CONEDIST1: 0.0000000000e+000

CONEDIST2: 0.0000000000e+000

CONEANGLE: 0.0000000000e+000

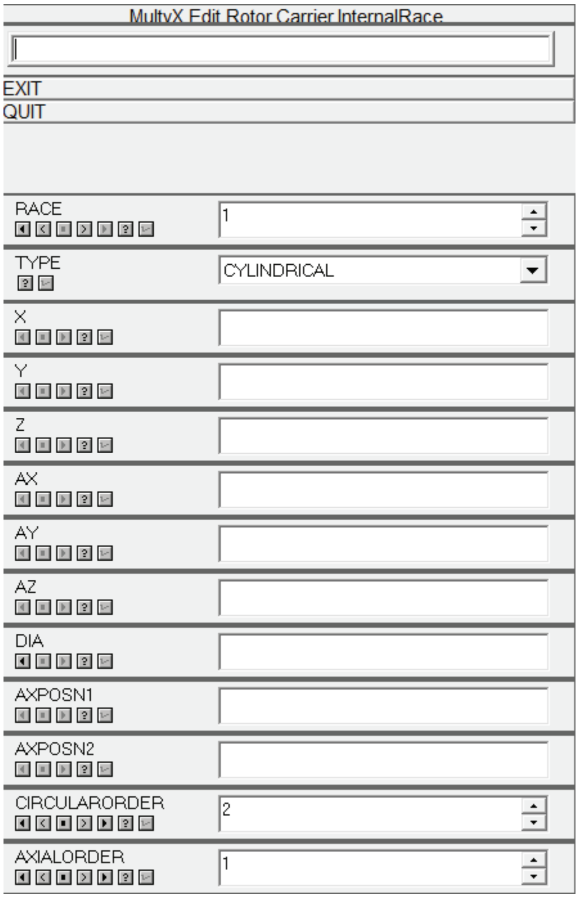
CIRCORDER: 2

AXIALORDER: 2

Figure 5.120 The race submenu for the conical race type.

tion for any races that are axially symmetric (i.e. cylindrical or conical races with the same rotational axis as the rotor). NRACES sets the number of races to be included. Each carrier must contain at least one race.

Figures 5.119 and 5.120 show the menu inputs for each race type. To define a cylindrical race surface on the carrier, the DIA of the race surface, AXPOSN1, and AXPOSN2 must be defined. To define a conical race surface, the ZAPEX (position of cone apex relative to the carrier origin), CONEDIST1, CONEDIST2, and CONEANGLE must be defined. The cone angle is the half cone angle from the rotational axis. CIRCORDER and AXIALORDER set the circular and axial Fourier series orders for interpolation between elements.



RACE 1

TYPE CYLINDRICAL

CIRCULARORDER 2

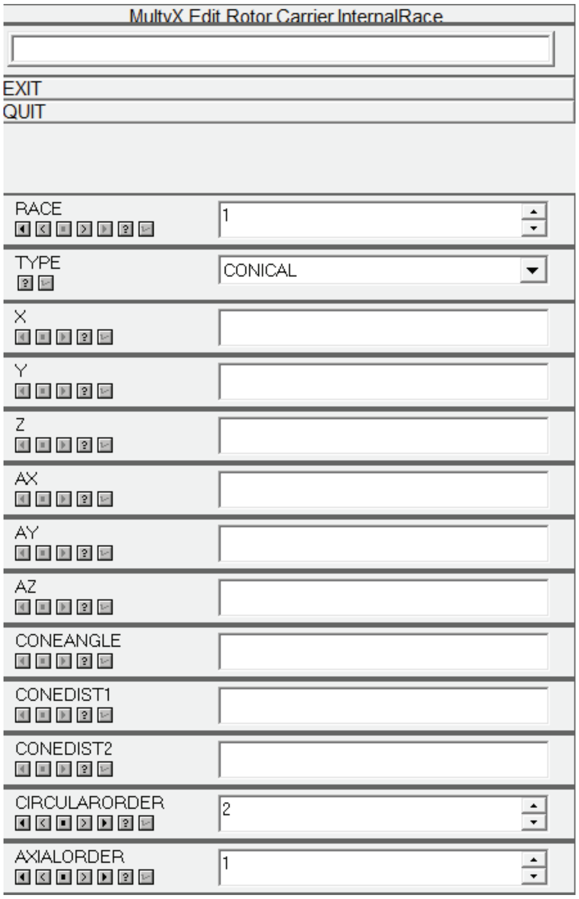
AXIALORDER 1

Figure 5.121 The race submenu for the cylindrical internal race type.

5.8.3.4 The INTERNALRACE Menu Selection of the ENABLEINTERNALRACE box activates the INTERNALRACE submenu of the carrier menu. Internal races are surfaces on the carrier where the user would like to attach a component, but the race surface axis of symmetry with the carrier rotational axis. Often this need arises when the carrier is made up of multiple components which are not connected to each other prior to exporting from the external FEA software. The internal race menus are similar to the RACE menu inputs mentioned above, with the exception that the race reference frame origin and orientation must be defined since it is different from the carrier reference frame. The X, Y, & Z inputs position the reference frame origin, while the AX, AY, and AZ inputs define the unit vector in the direction of the rotational axis. All remaining inputs are as described in the previous section.

5.8.3.5 The CONTACTSURFACE Menu Contact surfaces can be modeled on the carrier by selecting the ENABLECONTACTSURFACE box. When enabled, the CONTACTSURFACE submenu appears within the carrier menu. Two types of contact surfaces are able to be modeled: a planar surface, or a cylindrical surface. The contact surface menu arrangements for each of the two types is shown in Figures 5.123 and 5.124. The SOLIDID is the component ID exported from the FEA software on which the contact surface is being modeled. To model contact between two components within the same FE file, each component must have a separate ID so that the surfaces are distinguishable. If only one component exists, or if only one contact surface is being modeled on the carrier then the INCLUDEALLSOLIDS box may be selected. The origin of the contact surface is set for both surface types with the XPOS, YPOS, and ZPOS inputs.

The planar contact surface is modeled by defining a vector in the direction normal to the plane surface and a vector in the direction the plane's x-axis. The plane size is then set along the defined x-axis and the y-axis, which is perpendicular to both the normal and x-axis. The normal vector is described by the 3 component


MultyX Edit Rotor Carrier InternalRace
EXIT
QUIT
X
Y
Z
AX
AY
AZ
CONEANGLE
CONEDIST1
CONEDIST2

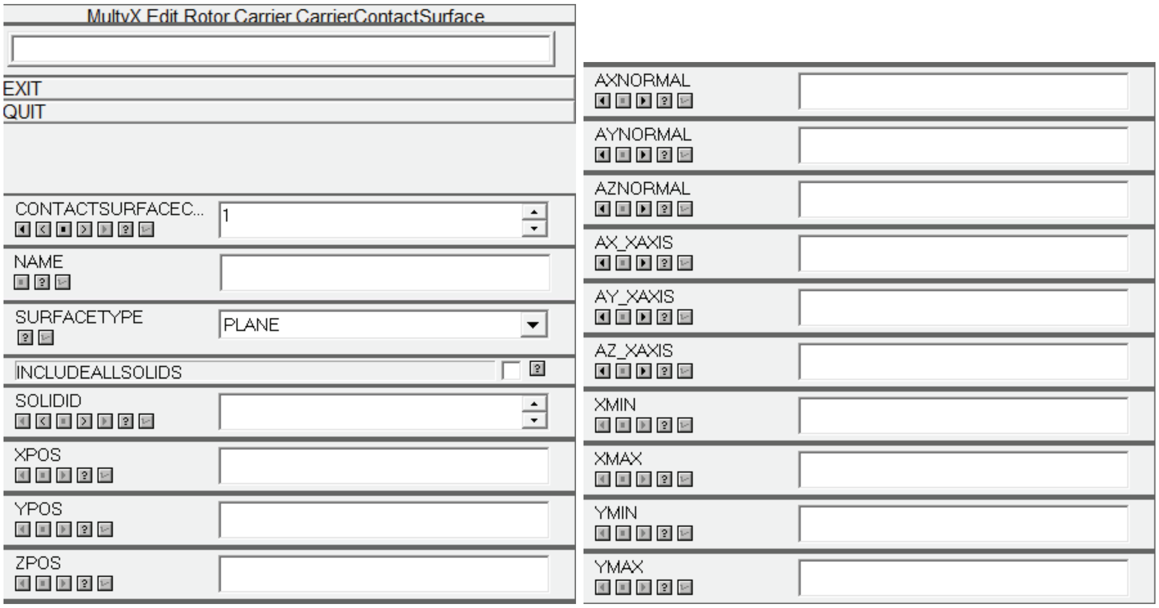
RACE: 1

TYPE: CONICAL

CIRCULARORDER: 2

AXIALORDER: 1

Figure 5.122 The race submenu for the conical internal race type.


MultyX Edit Rotor Carrier CarrierContactSurface

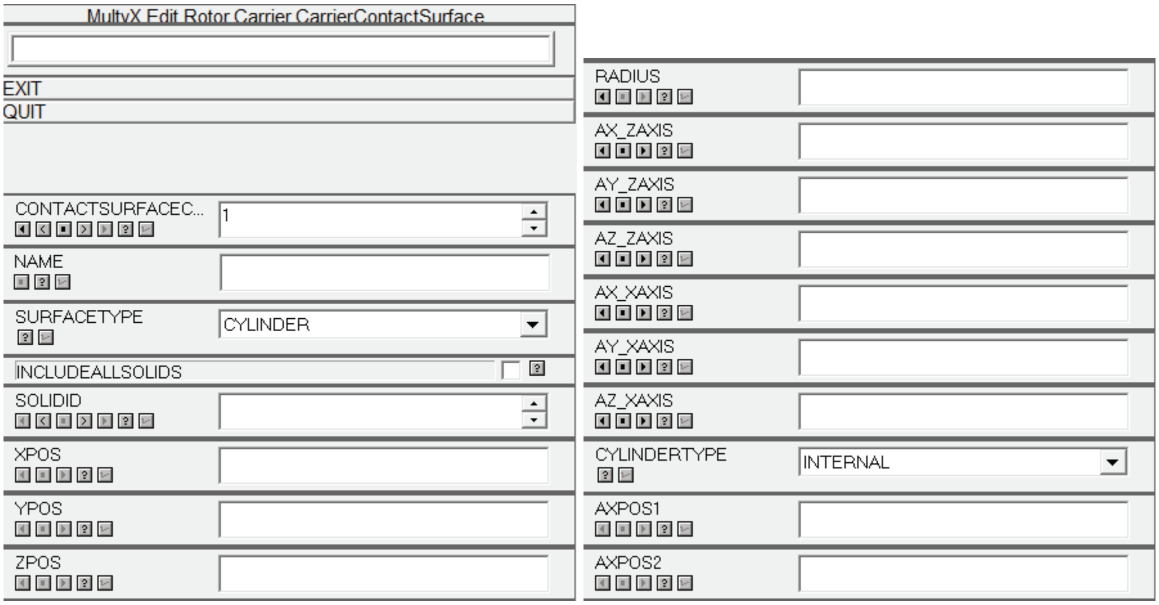
CONTACTSURFACEC... 1

SURFACETYPE PLANE

INCLUDEALLSOLIDS ☐

EXIT
QUIT
NAME
SOLIDID
XPOS
YPOS
ZPOS
AXNORMAL
AYNORMAL
AZNORMAL
AX_XAXIS
AY_XAXIS
AZ_XAXIS
XMIN
XMAX
YMIN
YMAX

Figure 5.123 The contact surface menu when the surface type is set to plane.


MultyX Edit Rotor Carrier CarrierContactSurface

CONTACTSURFACEC... 1

SURFACETYPE CYLINDER

INCLUDEALLSOLIDS ☐

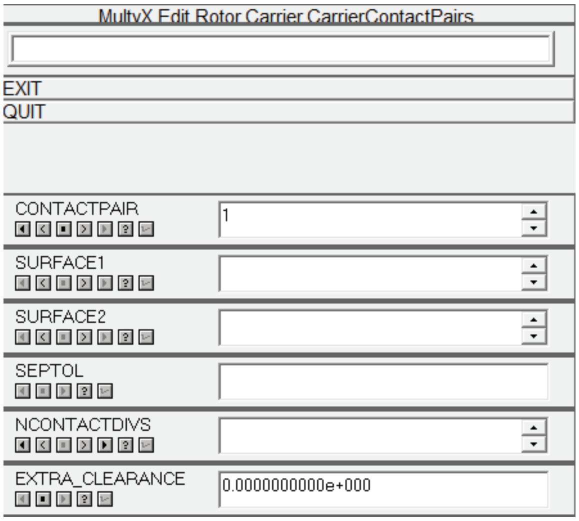
CYLINDERTYPE INTERNAL

EXIT
QUIT
NAME
SOLIDID
XPOS
YPOS
ZPOS
RADIUS
AX_ZAXIS
AY_ZAXIS
AZ_ZAXIS
AX_XAXIS
AY_XAXIS
AZ_XAXIS
AXPOS1
AXPOS2

Figure 5.124 The contact surface menu when the surface type is set to cylinder.

inputs AXNORMAL, AYNORMAL, and AZNORMAL, and the x-axis vector is similarly described by the AX_XAXIS, AY_XAXIS, and AZ_XAXIS. The minimum and maximum distances of the plane from the origin along the x and y axis are determined by the XMIN, YMIN, XMAX, and ZMAX inputs.

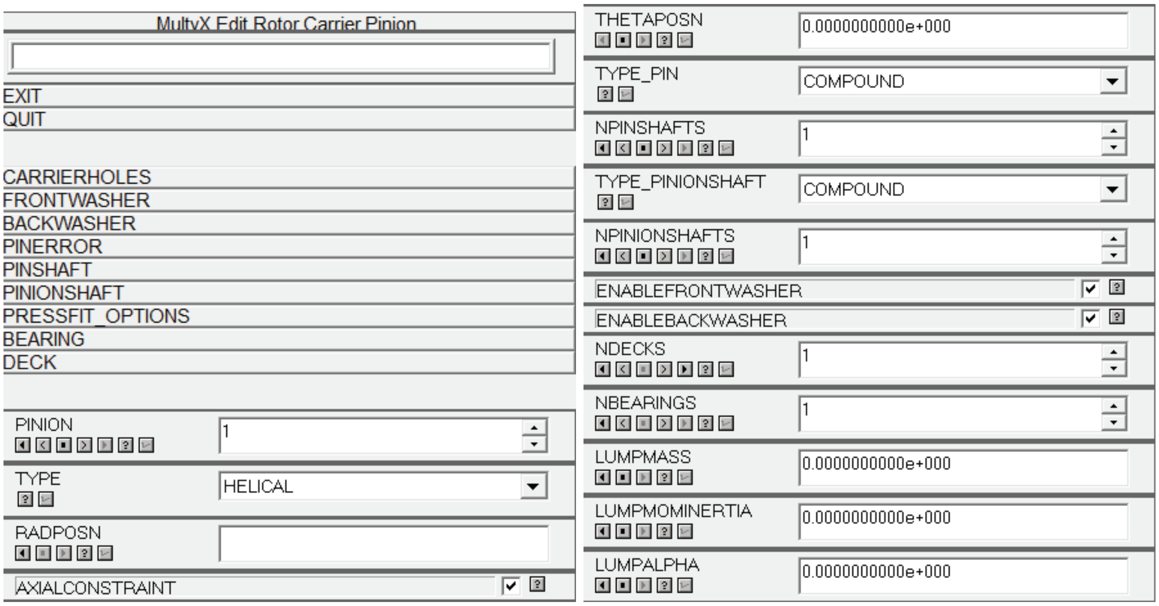
The cylindrical contact surface is modeled by entering the RADIUS of the cylindrical surface, as well as defining the z-axis of symmetry and x-axis in a similar manner to the planer surface. The cylindrical surface also requires the user to select whether to model the contact on the inside (CYLINDERTYPE=INTERNAL) or outside (CYLINDERTYPE=EXTERNAL) of the cylinder. Lastly, the length of the cylinder is set by entering the axial position of each end relative to the origin (AXPOS1 and AXPOS2).



CONTACTPAIR: 1
SURFACE1:
SURFACE2:
SEPTOL:
NCONTACTDIVS:
EXTRA_CLEARANCE: 0.0000000000e+000

Figure 5.125 The FE carrier contact pairs menu.

5.8.3.6 The CONTACTPAIRS Menu The contact pairs menu becomes active when the ENABLECONTACTPAIRS box is selected. This menu is used to define contact between two contact surfaces created within the CONTACTSURFACES menu. The contact pair menu inputs are shown in Figure 5.125. The surfaces to pair are SURFACE1 and SURFACE2. The maximum distance between the two surfaces to be considered 'in contact' is set by the SEPTOL input. NCONTACTDIVS sets the contact grid resolution from 1 to 4 and EXTRA_CLEARANCE is an additional clearance applied to the two surfaces. A negative clearance can be applied if a preload is desired.



PINION 1

TYPE HELICAL

RADPOSN

AXIALCONSTRAINT ☑

THETAPOSN 0.0000000000e+000

TYPE_PIN COMPOUND

NPINSHAFTS 1

TYPE_PINIONSHAFT COMPOUND

NPINIONSHAFTS 1

ENABLEFRONTWASHER ☑

ENABLEBACKWASHER ☑

NDECKS 1

NBEARINGS 1

LUMPMASS 0.0000000000e+000

LUMPMOMINERTIA 0.0000000000e+000

LUMPALPHA 0.0000000000e+000

Figure 5.126 The menu for specifying the helical pinion data.

5.9 Pinions

If the ENABLEPINIONS flag is checked, then the carrier can carry pinions. Within the carrier menu (Figure 5.112), NPINIONS is the number of *different types* of pinions. The PINION button in the carrier menu leads to the pinion menu. The item PINION selects the individual pinion for which the remaning data is displayed. The TYPE of the pinion can be either HELICAL or BEVEL. The details for modeling each of these types are provided in the subsequent sections.

5.9.1 Helical Pinions

The PINION menu for the HELICAL pinion type is shown in Figure 5.126. With the CARRIERTYPE set to FECARRIER, the CARRIERHOLES submenu is visible. This menu is used to model the races for the carrier-pin interfaces. The TYPE_PIN and TYPE_PINIONSHAFT inputs should be set to compound, as the SIMPLE pin and pinion shaft types are obsolete. With the compound pin and pinion shaft options are selected, the PINSHAFT and PINIONSHAFT submenus appear within the pinion menu. The BEARING menu also appears under this condition, and this should be used to model the pinion bearing instead of the connectors menu. Washers can be modeled to provide a contact surface between the carrier and side(s) of the pinion by selecting the ENABLEFRONTWASHER or ENABLEBACKWASHER boxes. Selection of one or both of these options results in the corresponding washer submenu(s) becomming active. The DECK submenu contains the inputs for the pinion decks, rim, tooth, and pinion errors. Table 5.36 provides a description of each of the helical pinion menu inputs.

5.9.1.1 Carrier Pin Hole Races The CARRIERHOLES submenu of the pinion menu is active when the carrier type is FECARRIER. This menu allows the user to define the race surfaces on the carrier holes for either a cantilevered pin or a pin supported on both ends. The hole radii are entered into the FRONTRADIUS and BACKRADIUS fields, and the hole front/back sides are defined with the Z1, Z2, Z3, and Z4 inputs. The race interface can be modeled as rigid, or flexible. If flexible, the circular and axial orders of the the Fourier series coefficients are entered. A brief description of each of the carrierholes menu inputs, as well as the condition for which each is active, is provided in Table 5.37.

Table 5.36 The Pinion menu for Helical Pinions

Item	Description
PINION	Integer, Pinion number
RADPOSN	Float, Radial position of the pinion on the carrier
THETAPOSN	Float, Angular postion of the pinion group
TYPE_PIN	Switch, The type of pin shaft (Use Compound)
NPINSHAFTS	Integer, The number of pin shafts
TYPE_PINIONSHAFT	Switch, The type of pinion shaft (Use Compound)
NPINIONSHAFTS	Integer, The number of pinion shafts
ENABLEFRONTWASHER	Boolean, Allows for modeling of washer on the back (-z) side of pinion
ENABLEBACKWASHER	Boolean, Allows for modeling of washer on the front (+z) side of pinion
NDECKS	Integer, Number of decks in the pinion
NBEARINGS	Integer, Number of pinion bearings
LUMPMASS	Float, Lumped mass at the pinion center
LUMPMOMINERTIA	Float, Lumped polar moment of inertia J_z at the pinion center
LUMPALPHA	Float, Damping constant alpha for the lumped mass

5.9.1.2 Pinion Decks A helical pinion can be built from a number of decks stacked in the axial direction. Each deck has its own involute geometry, but all decks move together as a single component. A carrier with two pinions, each with one deck is shown in Figure 5.127. For this system, NPINIONS is 2, and NDECKS is 1 for each of those two pinions.

An example of a 2 deck pinion is shown in Figure 5.128. For this carrier, NPINIONS is 1, but NDECKS is 2.

Figure 5.129 is an example of a pinion with 3 decks arranged in the axial direction. Again, NPINIONS is 1 and NDECKS is 3.

The DECK command in Figure 5.126 leads to the pinion deck menu as shown in Figure 5.130. The DECK item in this menu selects the individual deck for which subsequent data and sub-menus are displayed. CIRCORDER and AXIALORDER are the Fourier series orders for the base surface of the deck. ENABLEFRONTDORSET and ENABLEBACKDOFSET allow the user to model a race surface on the front and/or back of the pinion deck, respectively. Selecting one or both of these activates the FRONTSHOULDERDIA/BACKSHOULDERDIA inputs. These diameters define the maximum diameter of the race interface on the respective deck surface.

There are 6 submenus in the DECK menu: TOOTH, RIM, SPACEERR, RUNOUT, SKEW, and LEADERROR.

Figure 5.131 shows a pinion with 2 decks. Figure 5.132 shows two pinions with 1 deck.

Table 5.37 The Carrierholes Menu Inputs

Item	Description
ISCANTILEVEREDPINPINION	Boolean, If enabled, a pin supported on only one side will be modeled
CANTILEVEREDSIDEPINPINION	Switch, Side of pinion pin supported. It may be FRONT or BACK. (Active if ISCANTILEVEREDPINPINION=TRUE)
BACKRADIUS	Float, Radius of the back (-z) side of the pin. (Active if (ISCANTILEVEREDPINPINION=TRUE & CANTILEVEREDSIDEPINPINION=BACK) or ISCANTILEVEREDPINPINION=FALSE)
FRONTRADIUS	Float, Radius of the front (+z) side of the pin. (Active if (ISCANTILEVEREDPINPINION=TRUE & CANTILEVEREDSIDEPINPINION=FRONT) or ISCANTILEVEREDPINPINION=FALSE)
Z1	Float, The axial distance from the carrier origin to the back of the back carrier hole. If cantilevered, z1 is to back side carrier pin hole.
Z2	Float, The axial distance from the carrier origin to the front of the back carrier hole. If cantilevered, z1 is to front side of carrier pin hole.
Z3	Float, The axial distance from the carrier origin to the back of the front carrier hole. (Active if ISCANTILEVEREDPINPINION=FALSE)
Z4	Float, The axial distance from the carrier origin to the front of the front carrier hole.(Active if ISCANTILEVEREDPINPINION=FALSE)
RIGIDINTERFACE	Boolean, Models the carrier-pin interface as a rigid connection.
CIRCORDERBACK	Integer, Circular order of the back carrier hole race. (Active if RIGIDINTERFACE=FALSE)
AXIALORDERBACK	Integer, Axial order of the back carrier hole race. (Active if RIGIDINTERFACE=FALSE)
CIRCORDERFRONT	Integer, Circular order of the front carrier hole race. (Active if RIGIDINTERFACE=FALSE) and ISCANTILEVEREDPINPINION=FALSE)
AXIALORDERFRONT	Integer, Axial order of the front carrier hole race. (Active if RIGIDINTERFACE=FALSE) and ISCANTILEVEREDPINPINION=FALSE)

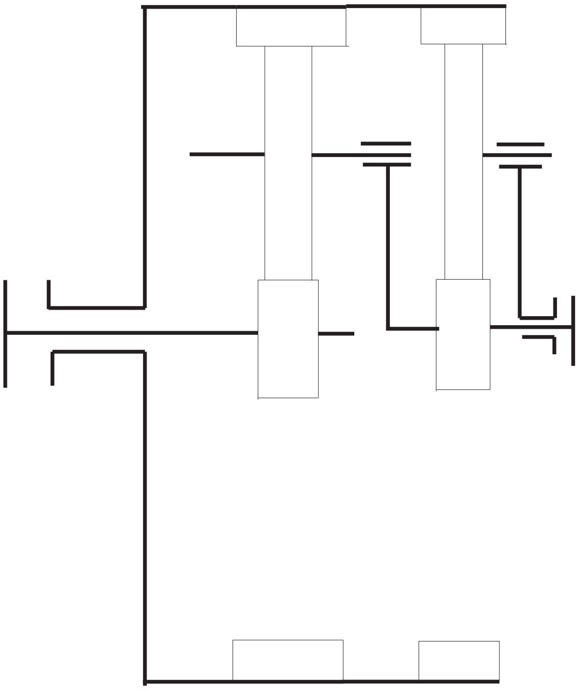


Figure 5.127 A planetary system schematic showing a carrier with two pinions each with a single deck.

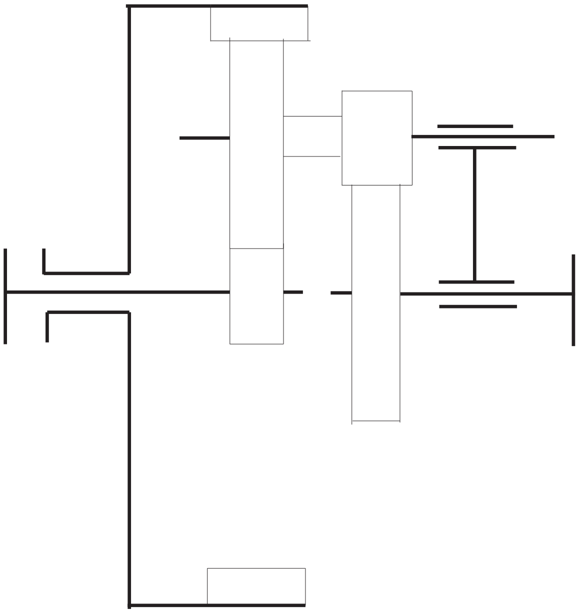


Figure 5.128 A planetary system schematic showing a carrier with one pinion consisting of 2 decks

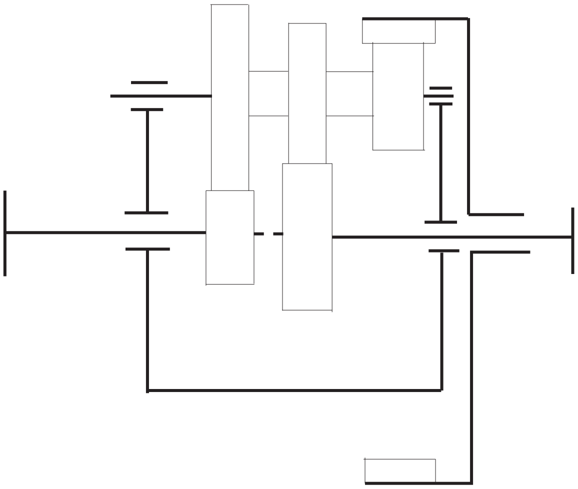
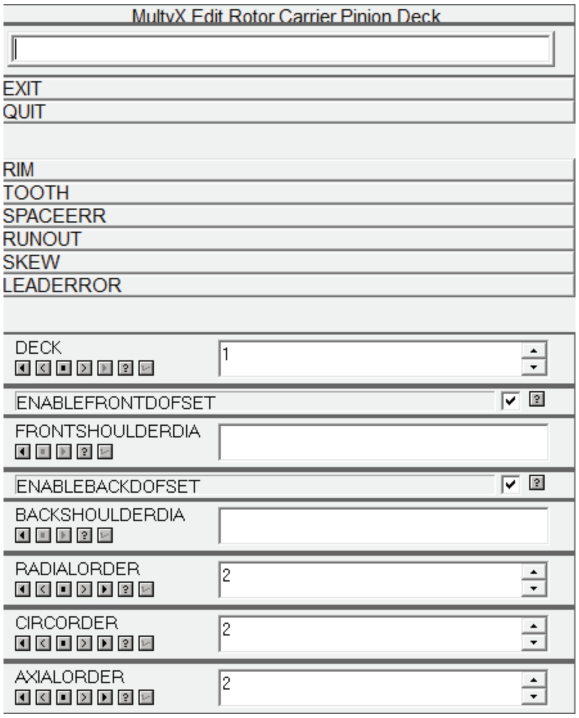


Figure 5.129 A planetary system schematic showing a carrier with one pinion consisting of 3 decks



MultyX Edit Rotor Carrier Pinion Deck
EXIT
QUIT
RIM
TOOTH
SPACEERR
RUNOUT
SKEW
LEADERROR

DECK 1

ENABLEFRONTDOFSET ☑

FRONTSHOULDERDIA

ENABLEBACKDOFSET ☑

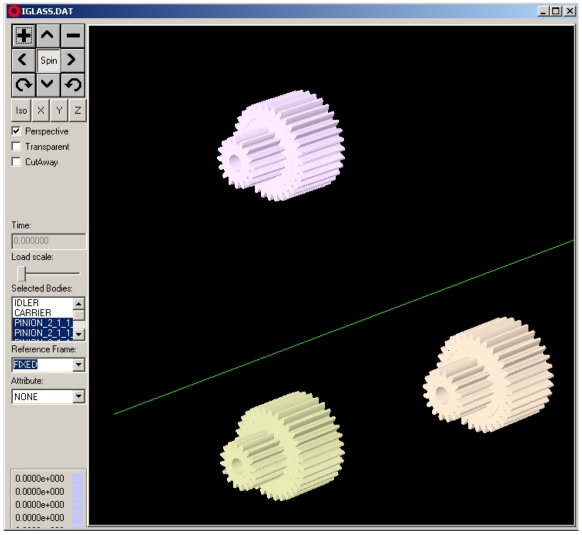
BACKSHOULDERDIA

RADIALORDER 2

CIRCORDER 2

AXIALORDER 2

Figure 5.130 The menu for specifying the deck data.



☑ Perspective
☐ Transparent
☐ CutAway

Time: 0.000000

Load scale:

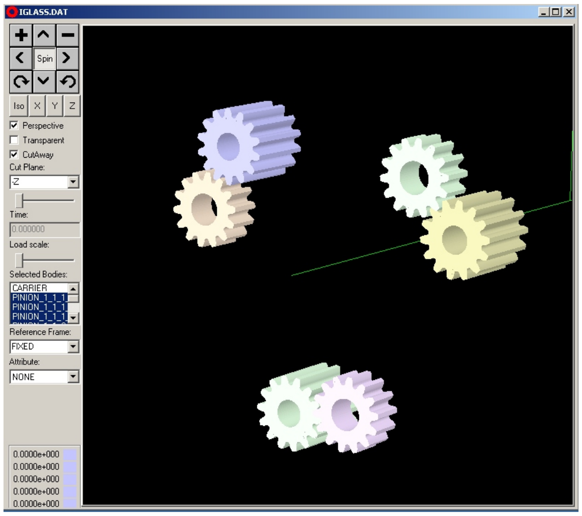
Selected Bodies:
IDLER
CARRIER
PINION_2_1_1
PINION_2_1_1

Reference Frame: FIXED

Attribute: NONE

0.0000e+000
0.0000e+000
0.0000e+000
0.0000e+000

Figure 5.131 A pinion with 2 decks.



☑ Perspective
☐ Transparent
☑ CutAway

Cut Plane: -Z

Time: 0.000000

Load scale:

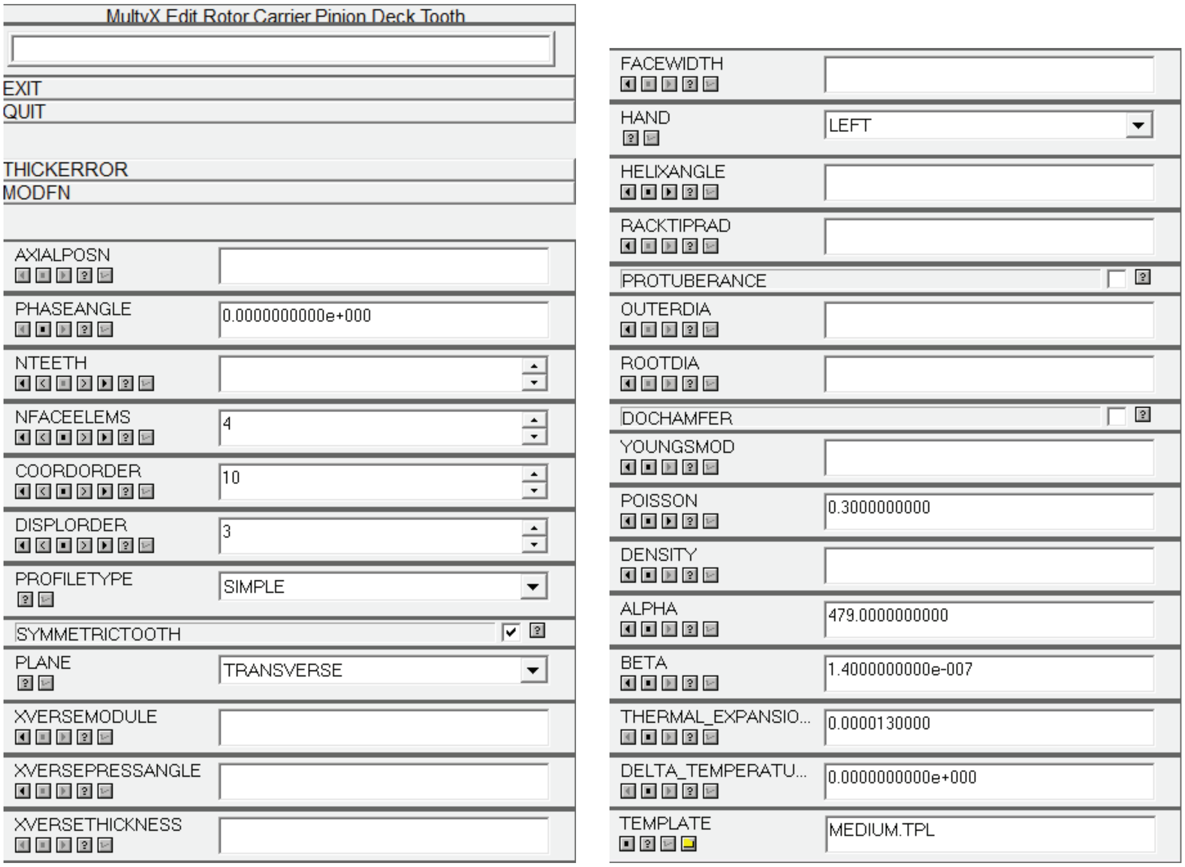
Selected Bodies:
CARRIER
PINION_1_1_1
PINION_1_1_1
PINION_1_1_1

Reference Frame: FIXED

Attribute: NONE

0.0000e+000
0.0000e+000
0.0000e+000
0.0000e+000
0.0000e+000

Figure 5.132 Two pinions with 1 deck.



AXIALPOSN	
PHASEANGLE	0.0000000000e+000
NTEETH	
NFACEELEMS	4
COORDORDER	10
DISPLORDER	3
PROFILETYPE	SIMPLE
SYMMETRICTOOTH	☑
PLANE	TRANSVERSE
XVERSEMODULE	
XVERSEPRESSANGLE	
XVERSETHICKNESS	
FACEWIDTH	
HAND	LEFT
HELIXANGLE	
RACKTIPRAD	
PROTUBERANCE	☐
OUTERDIA	
ROOTDIA	
DOCHAMFER	☐
YOUNGSMOD	
POISSON	0.3000000000
DENSITY	
ALPHA	479.0000000000
BETA	1.4000000000e-007
THERMAL_EXPANSIO...	0.0000130000
DELTA_TEMPERATU...	0.0000000000e+000
TEMPLATE	MEDIUM.TPL

Figure 5.133 The helical pinion tooth menu.

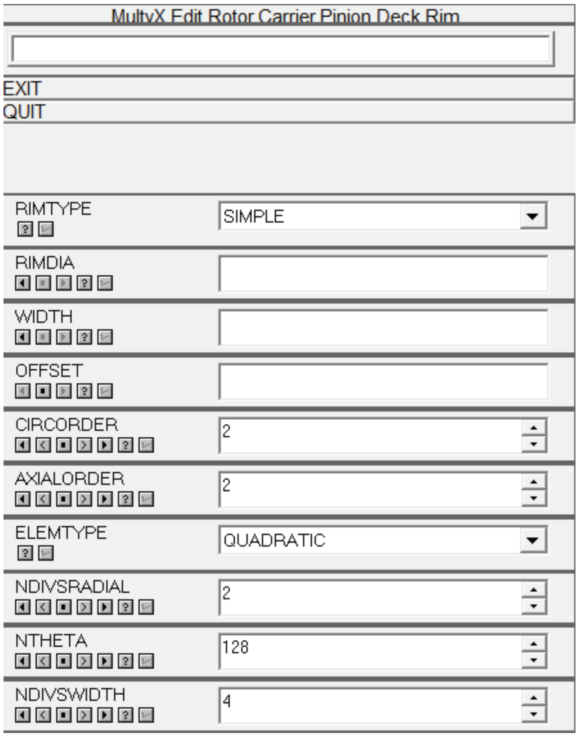
5.9.1.3 Modeling the Pinion tooth The TOOTH command in Figure 5.130 leads to the Pinion tooth menu as shown in Figure 5.133. An axial position for each deck is specified in the AXIALPOSN item. It is measured at the mid face cross section of the deck of the pinion, relative to the rotor origin. In a multiple deck pinion each deck can be placed at a different phase angle with respect to the pinion axis. This angle is specified in PHASEANGLE. When it is zero for all decks, the tooth center lines at the mid-face cross sections of tooth no. 1 of all decks line up with one another. Tables 5.38 and 5.39 explains all the parameters associated with the Pinion tooth menu. The tooth modification menu for the pinion tooth is similar to that of the sun/ring gear tooth modification menu.

Table 5.38 Pinion tooth menu (1 of 2)

Item	Description	Condition
AXIALPOSN	Integer, Axial position of the pinion deck, measured at the midface cross section	
PHASEANGLE	Float, The phase angle (Deg) of the various decks in the multiple decks pinion	
NTEETH	Integer, The number of teeth on deck of the pinion	
NFACEELEMS	Integer, The number of elements across the face width of the pinion deck	
COORDORDER	Integer, Limit on order of coord axodes for the pinion deck	
DISPLORDER	Integer, Limit on displ. order of axodes for the pinion deck	
PROFILETYPE	Switch, Type of profile to use for the pinion. SIMPLE creates a simple hobbed involute geometry, NUMERICAL allows the user to specify the profile through a data file. FORMGROUND is similar to simple, but the edge radius is applied to the grinding wheel instead of to the hob.	
SYMMETRICTOOTH	Boolean, Makes basic tooth geometry symmetric. Disabling activates the TOOTHSIDE submenu, where the tooth menu inputs related to tooth symmetry can be entered separately for each side. Tooth modifications can be assymetric regardless of this input.	
PLANE	Switch, The plane used to define DP., P.A. and thickness. This switch can be set to one of the two options: NORMAL or TRANSVERSE	
NORMALDIAMPITCH	Float, The normal gen. diametral pitch	if(PLANE=NORMAL)
NORMALPRESSANGLE	Float, The normal gen. press. angle (Deg)	if(PLANE=NORMAL) if(SYMMETRICTOOTH=TRUE)
NORMALTHICK	Float, Normal thickness of the gear tooth	if(PLANE=NORMAL)
XVERSEDIAMPITCH	Float, The xverse gen. diametral pitch	if(PLANE≠NORMAL)
XVERSEPRESSANGLE	Float, The xverse gen. press. angle (Deg)	if(PLANE≠NORMAL) if(SYMMETRICTOOTH=TRUE)
XVERSETHICK	Float, Transverse thickness of the gear tooth	if(PLANE≠NORMAL)
FACEWIDTH	Float, The face width of the pinion deck	

Table 5.39 Pinion tooth menu (2 of 2)

Item	Description	Condition
HAND	Switch, The hand of the pinion deck (Left/Right)	
HELIXANGLE	Float, The helix angle of the pinion deck	
RACKTIPRAD	Float, Rack tip radius for the pinion deck	if(SYMMETRICTOOTH=TRUE)
PROTUBERANCE	Boolean, If this flag is enabled, then a protuberance can be specified on the hob.	if(SYMMETRICTOOTH=TRUE)
OUTERDIA	Float, Outer dia. of the pinion deck	
ROOTDIA	Float, Root dia.of the pinion deck	
RIMDIA	Float, Rim dia. of the pinion deck	if(RIMTYPE≠NONE)
INNERDIA	Float, Inner dia of the pinion deck	if(RIMTYPE=NONE)
DOCHAMFER	Boolean, If this flag is enabled, then chamfer will be generated at the tooth tip.	if(SYMMETRICTOOTH=TRUE)
YOUNGSMOD	Float, Young’s modulus for the pinion deck	
POISSON	Float, Poisson’s ratio for the pinion deck	
DENSITY	Float, Density of the pinion deck	
ALPHA	Float, The Raleigh damping model assumes that the damping matrix C for a finite element is is related to the Mass matrix M and stiffnes matrix K by the linear relationship C=alpha*M+beta*K The variable ALPHA is the value of alpha.	
BETA	Float, The Raleigh damping model assumes that the damping matrix C for a finite element is is related to the Mass matrix M and stiffnes matrix K by the linear relationship C=alpha*M+beta*K The variable BETA is the value of beta.	
THERMAL_EXPANSION	Float,	
DELTA_TEMPERATURE	Float,	
TEMPLATE	String, Template file name for pinion deck	


MultyX Edit Rotor Carrier Pinion Deck Rim

EXIT

QUIT

RIMTYPE SIMPLE

RIMDIA

WIDTH

OFFSET

CIRCORDER 2

AXIALORDER 2

ELEMTYPE QUADRATIC

NDIVSRADIAL 2

NTHETA 128

NDIVSWIDTH 4

Figure 5.134 The Simple type pinion rim menu.

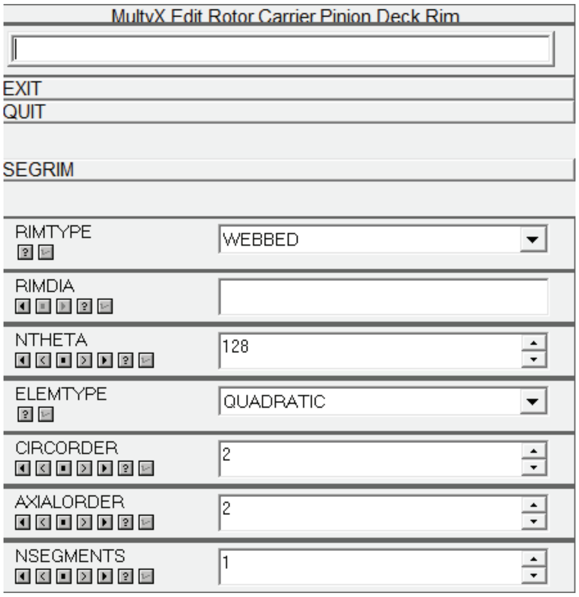
5.9.1.4 Modeling the Pinion Rim The RIM command in Figure 5.130 leads to the Pinion rim menu. Figures 5.134 and 5.135 show the SIMPLE and WEBBED type rim menus respectively. The rim parameters for both the SIMPLE and WEBBED rim menus are similar to those used for the Sun gears. Figure 5.136 shows webbed rims for the 2 decks of a pinion.

5.9.1.5 Modeling Pinion Washers Washers can be included on the front or back side of the pinion by selecting the ENABLEFRONTWASHER or ENABLEBACKWASHER boxes in the pinion menu, respectively. The front and back washer menu inputs appear as shown in Figure 5.137. The AXIALPOSN input sets the axial distance from the carrier origin to the washer-carrier interface. The THICKNESS, INNERDIA, and OUTERDIA inputs define the washer geometry. The race at the washer-carrier interface is automatically created when the interface location is defined within the washer menu. The washer-pinion shaft contact pair must be defined within the pairs menu to model the contact.

5.9.1.6 The Pin and Pinion Shafts The carrier pin and pinion shaft are modeled within the PIN and PINIONSHAFT submenus respectively. We provide the details for modeling both within this section since both processes are nearly identical. The PIN and PINIONSHAFT menu inputs are shown in Figure 5.138. The AXIALPOSNSHAFT input sets the starting point for the first segment of the shaft. NSEGMENTS defines the number of segments to use to model the shaft. ENABLEBACKINTERFACE and ENABLEFRONTINTERFACE enable race surfaces on the back and/or front end(s) of the shaft, respectively. If enabled, the CIRCORDER and RADIALORDER Fourier series coefficients are specified for the race surface within the shaft menu.

The SEGMENT menu for TYPESEG=DEFINEGEOMETRY is shown in Figure 5.139. The menu structure for this pin or pinion shaft type is identical to the segment menu for a typical rotor shaft segment. For a description of the inputs, refer to the rotor shaft menu section.

An FE pin or pin shaft segment can be imported by selecting FEMESH_NASTRAN or FEMESH_ABAQUS from the TYPESEG dropdown menu. Doing so changes the SEGMENT menu structure so that it appears similar to the one shown in Figure 5.140. The front and back diameter inputs set the inside and outside diame-



MultyX Edit Rotor Carrier Pinion Deck Rim

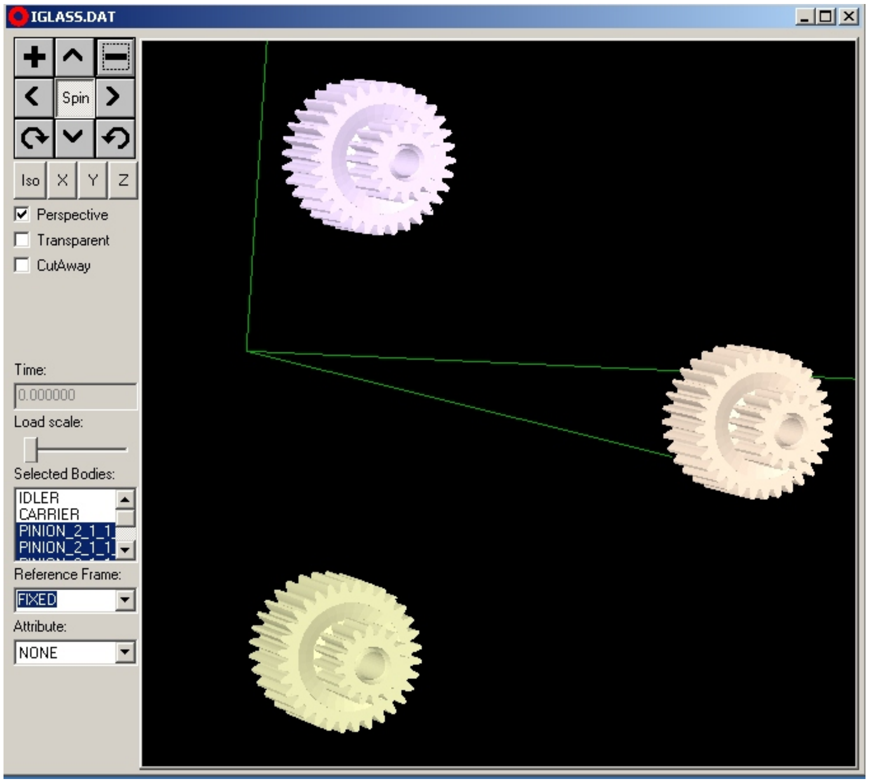
EXIT

QUIT

SEGRIM

RIMTYPE	WEBBED
RIMDIA	
NTHETA	128
ELEMTYPE	QUADRATIC
CIRCORDER	2
AXIALORDER	2
NSEGMENTS	1

Figure 5.135 The Webbed type pinion rim menu.



☑ Perspective

☐ Transparent

☐ CutAway

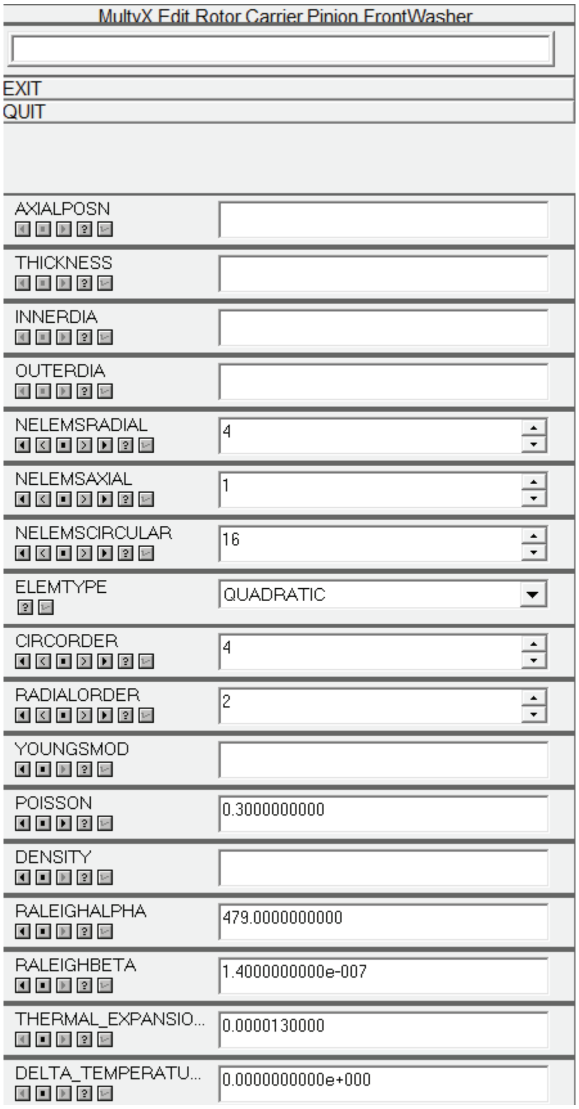
Time: 0.000000

Selected Bodies:
- IDLER
- CARRIER
- PINION_2_1_1
- PINION_2_1_1

Reference Frame: FIXED

Attribute: NONE

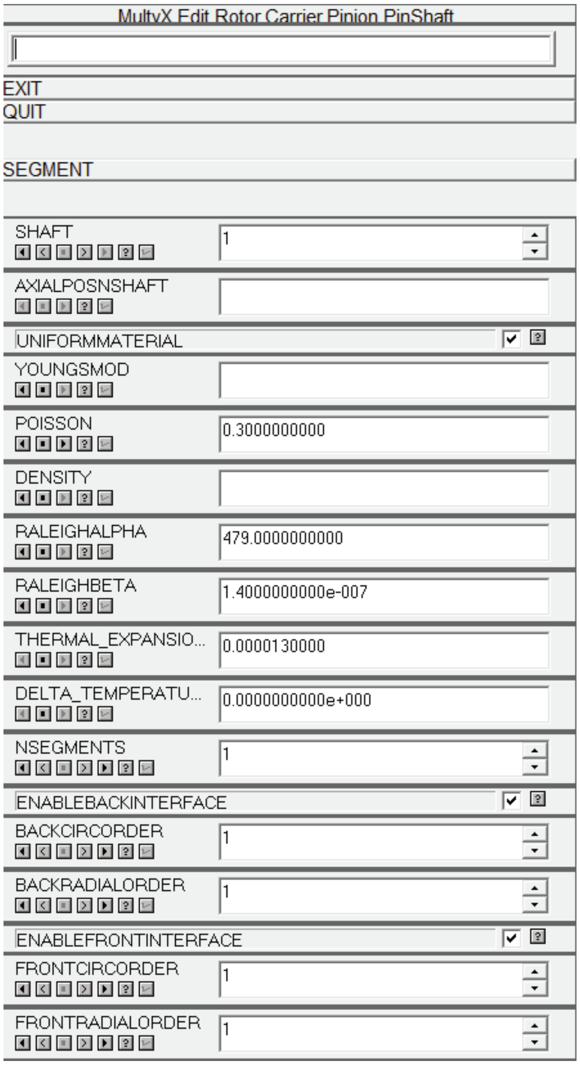
Figure 5.136 Example of a pinion with a webbed rim for each deck.



MultyX Edit Rotor Carrier Pinion FrontWasher

AXIALPOSN	
THICKNESS	
INNERDIA	
OUTERDIA	
NELEMSRADIAL	4
NELEMSAXIAL	1
NELEMSCIRCULAR	16
ELEMTYPE	QUADRATIC
CIRCORDER	4
RADIALORDER	2
YOUNGSMOD	
POISSON	0.3000000000
DENSITY	
RALEIGHALPHA	479.0000000000
RALEIGHBETA	1.4000000000e-007
THERMAL_EXPANSIO...	0.0000130000
DELTA_TEMPERATU...	0.0000000000e+000

Figure 5.137 The washers menu for helical pinions.



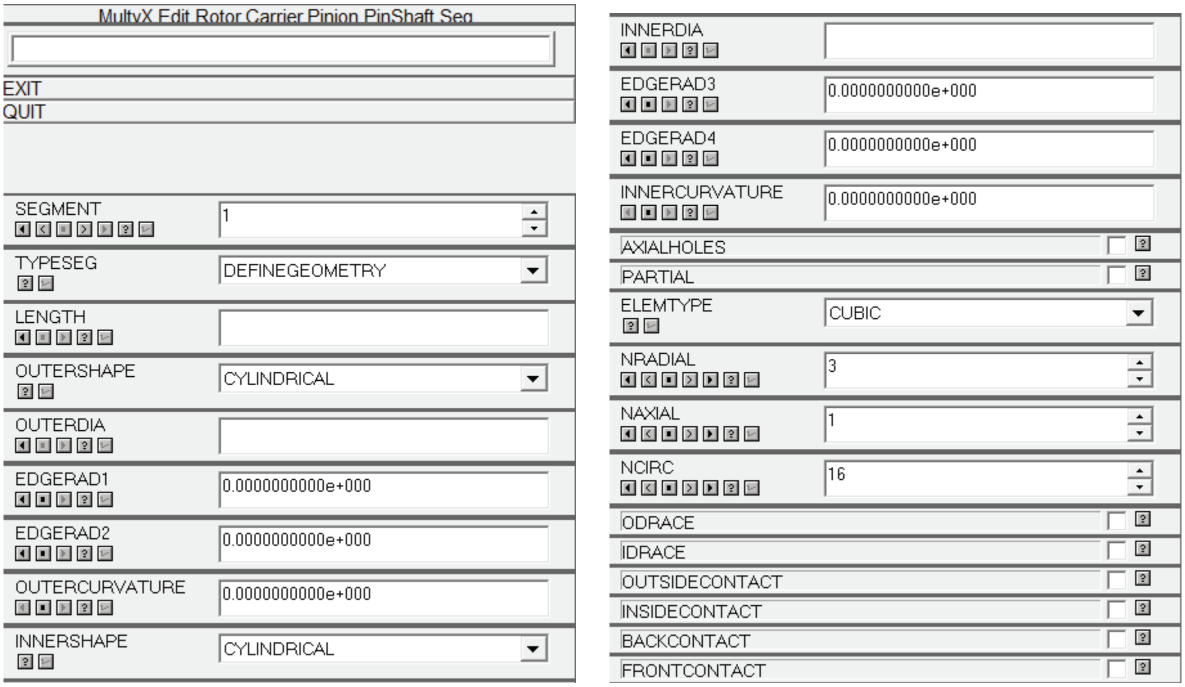
SHAFT	1
AXIALPOSNSHAFT	
UNIFORMMATERIAL	☑
YOUNGSMOD	
POISSON	0.3000000000
DENSITY	
RALEIGHALPHA	479.0000000000
RALEIGHBETA	1.4000000000e-007
THERMAL_EXPANSIO...	0.0000130000
DELTA_TEMPERATU...	0.0000000000e+000
NSEGMENTS	1
ENABLEBACKINTERFACE	☑
BACKCIRCORDER	1
BACKRADIALORDER	1
ENABLEFRONTINTERFACE	☑
FRONTCIRCORDER	1
FRONTRADIALORDER	1

Figure 5.138 The helical pinion pinshaft menu.

ters of the front/back of the shaft segment so that a race surface can be created to connect the segment to other segments/shafts. CIRCORDER and RADIALORDER sets the Fourier series coefficients for front/back race interfaces. The front side inputs are hidden when the segment is the last of a shaft and the back side inputs are hidden similarly when the segment is the first. If the ENABLEBACKINTERFACE option is enabled in the PINSHAFT/PINIONSHAFT menu, the back side diameter inputs are shown for the first segment. Similarly, if ENABLEFRONTINTERFACE is enabled, the front side diameter inputs are visible for the last segment. When ENABLEFRONTINTERFACE or ENABLEBACKINTERFACE are enabled, the orders are entered within the shaft menu, so the CIRCORDER and RADIALORDER inputs corresponding to these connecting surfaces are hidden within the segment menu.

Races can be added to the inner and outer surfaces of the shaft segment by selecting ENABLERACES. The number of races the user would like to add is then entered within the NRACES input field. The RACE submenu contains the inputs for desribing the additional races. These inputs are described in Table 5.40.

The FILE submenu (Figure 5.141) contains the inputs related to the *Nastran* or *ABAQUS* finite element files. The FE file is entered within the FILENAME input field. For *Nastran* files, the `.bdf` file extension should be used, while the `.inp` extension is accepted for *ABAQUS* files. SUBTREENAME is the label used for creating subfolders within the calyxtmp folder inside the model working directory.

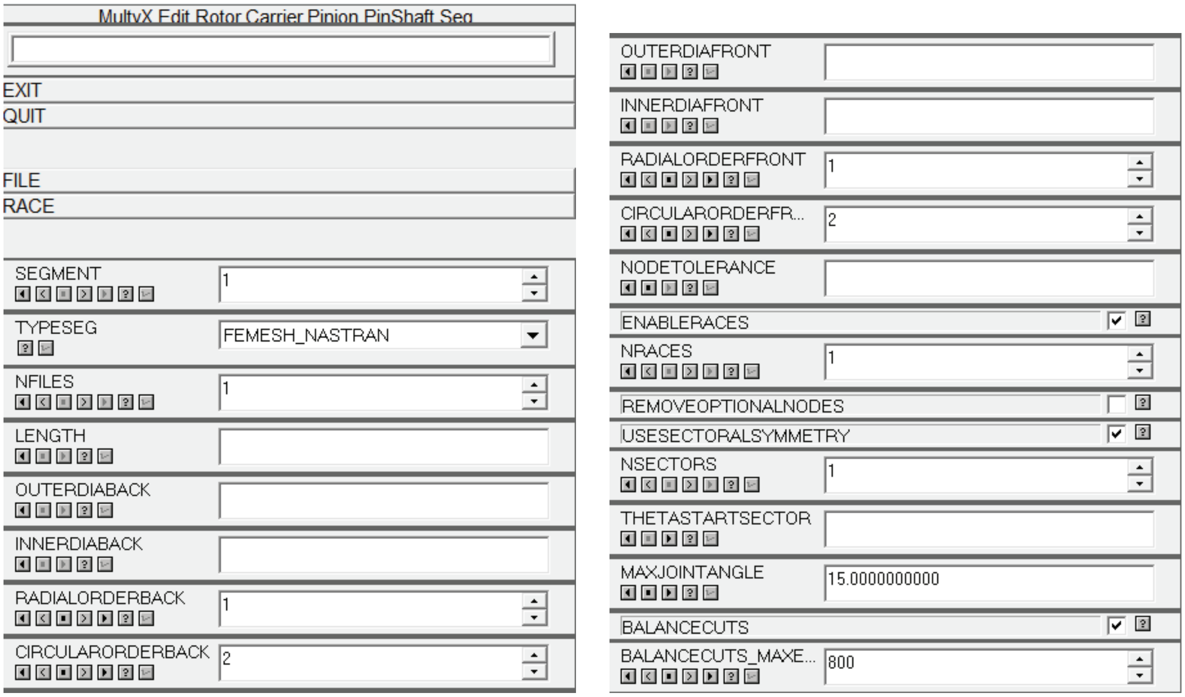


MultyX Edit Rotor Carrier Pinion PinShaft Seg

EXIT
QUIT

SEGMENT 1
TYPESEG DEFINEGEOMETRY
LENGTH
OUTERSHAPE CYLINDRICAL
OUTERDIA
EDGERAD1 0.0000000000e+000
EDGERAD2 0.0000000000e+000
OUTERCURVATURE 0.0000000000e+000
INNERSHAPE CYLINDRICAL
INNERDIA
EDGERAD3 0.0000000000e+000
EDGERAD4 0.0000000000e+000
INNERCURVATURE 0.0000000000e+000
AXIALHOLES ☐
PARTIAL ☐
ELEMTYPE CUBIC
NRADIAL 3
NAXIAL 1
NCIRC 16
ODRACE ☐
IDRACE ☐
OUTSIDECONTACT ☐
INSIDECONTACT ☐
BACKCONTACT ☐
FRONTCONTACT ☐

Figure 5.139 The helical pinion/pin shaft segment menu for the DEFINEGEOMETRY segment type.



MultyX Edit Rotor Carrier Pinion PinShaft Seg

EXIT
QUIT

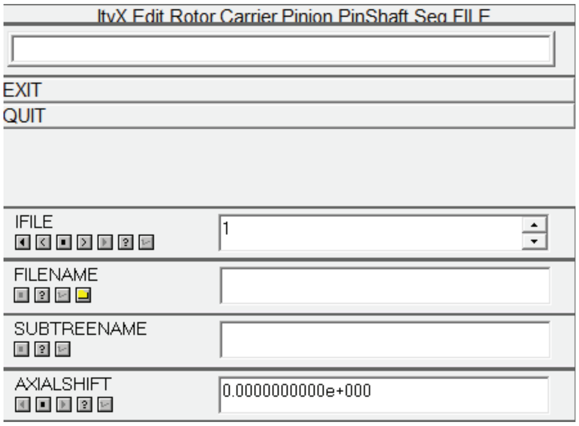
FILE
RACE

SEGMENT 1
TYPESEG FEMESH_NASTRAN
NFILES 1
LENGTH
OUTERDIABACK
INNERDIABACK
RADIALORDERBACK 1
CIRCULARORDERBACK 2
OUTERDIAFRONT
INNERDIAFRONT
RADIALORDERFRONT 1
CIRCULARORDERFR... 2
NODETOLERANCE
ENABLERACES ☑
NRACES 1
REMOVEOPTIONALNODES ☐
USESECTORALSYMMETRY ☑
NSECTORS 1
THETASTARTSECTOR
MAXJOINTANGLE 15.0000000000
BALANCECUTS ☑
BALANCECUTS_MAXE... 800

Figure 5.140 The helical pinion/pin shaft segment menu for the FEMESH segment type.

Table 5.40 Pin/Pinion Shaft Segment Race Menu Inputs

Item	Description	Condition
RACE	Integer, The race number to edit	
TYPE	Switch, The race type	
DIA	Float, Diameter of the race surface	if(TYPE=CYLINDRICAL)
AXPOSN1	Float, Axial position of the back side of the race, entered within the segment reference frame.	if(TYPE=CYLINDRICAL)
AXPOSN2	Float, Axial position of the front side of the race, entered within the segment reference frame.	if(TYPE=CYLINDRICAL)
ZAPEX	Float, Axial position of the cone apex of the race, entered within the segment reference frame.	if(TYPE=CONICAL)
CONEDIST2	Float, Distance from apex to smaller end of conical race surface.	if(TYPE=CONICAL)
CONEANGLE	Float, Distance from apex to larger end of conical race surface.	if(TYPE=CONICAL)
CIRCORDER	Float, Root dia.of the pinion deck	
AXIALORDER	Float, Rim dia. of the pinion deck	



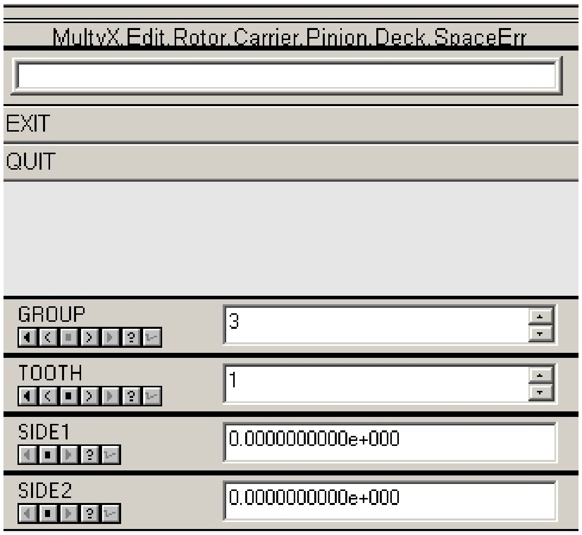
IFILE 1

FILENAME

SUBTREENAME

AXIALSHIFT 0.0000000000e+000

Figure 5.141 The helical pinion/pin shaft segment file menu.



GROUP 3

TOOTH 1

SIDE1 0.0000000000e+000

SIDE2 0.0000000000e+000

Figure 5.142 The pinion spacing error menu.

5.9.1.7 Modeling a Pinion Bearing The pinion BEARING menu is used to model the pinion bearing when the pin shaft and pinion shaft are both compound type shafts. There are 3 types of bearings available to the user: STIFFNESS, JOURNAL, or ROLLERS. The menu for each of these bearing types is identical to those described within the connectors section of this manual. For more detailed information on how to model the pinion bearing, refer to the connectors section.

5.9.1.8 Pinion, Pin, and Gear Errors Within the pinion menu, pin shaft and pinion tooth errors can be modeled. The options available currently are: pin posistion error, tooth spacing error, runout, skew, and lead error. These errors are described within the section titled ’Modeling Manufacturing Errors’. Please refer to this section for details on the related menu inputs.

5.9.2 Bevel Pinions

When the TYPE of the pinion is changed to BEVEL in the PINION menu (Figure 5.144), the bevel pinion menu appears. AXIALPOSN and PHIPOSN locate the pinion as shown in Figure 5.143. THETAPOSN locates the pinion about the axis (when THETAPOSN is zero, the pinion axis lies in the X-Z plane.) The remaining items in the bevel pinion menu serve the same purpose as that in the helical pinion menu.

The PINRACE submenu is visible when the CARRIERTYPE is set to FECARRIER. This menu defines the races at the pin-carrier interface.

The WASHER and CLEARANCEPINCARRIER submenus are visible when the ENABLEWASHER and ENABLE CLEARANCE PIN CARRIER boxes are selected, respectively. The WASHER menu contains the inputs for modeling a washer to constrain the redial motion of the pinion, while the CLEARANCEPINCARRIER menu contains the inputs for modeling a clearance connection at the bevel pinion.

If the TYPE_PINIONSHAFT is set to COMPOUND as recommended, the PINIONSHAFT and BEARING submenus become active. The compound pinion shaft and bearing inputs are entered into these two menus.

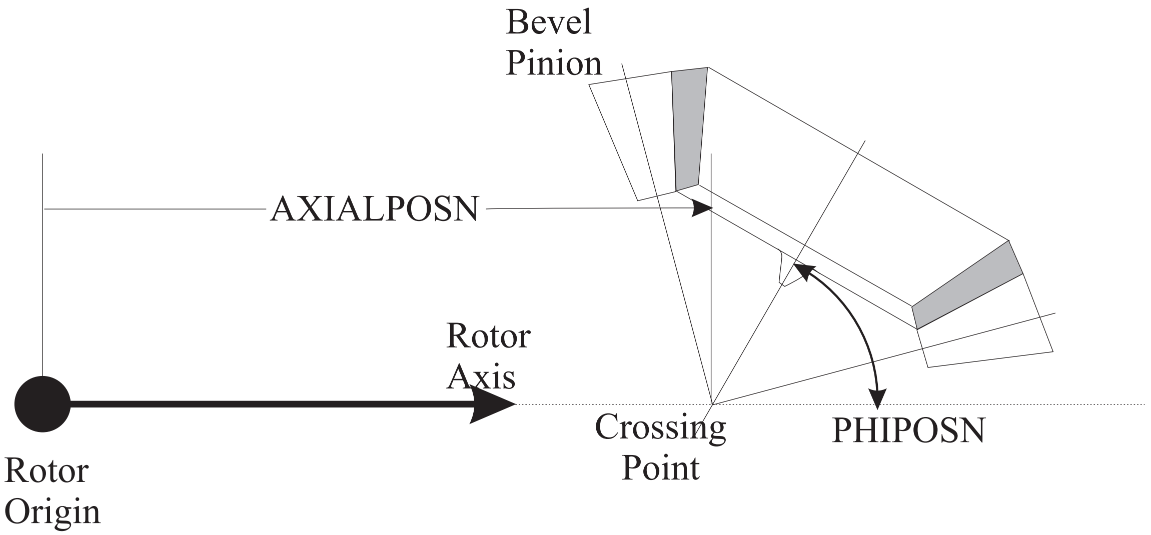
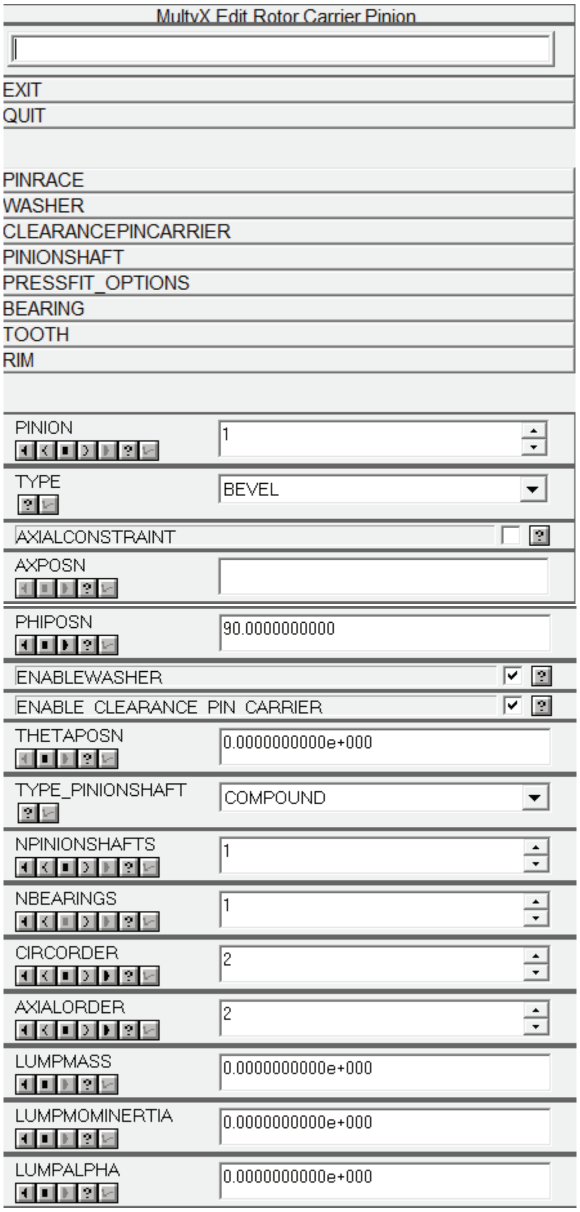


Figure 5.143 The location AXIALPOSN and orientation PHIPOSN of a bevel pinion in a carrier.


MultyX Edit Rotor Carrier Pinion
EXIT
QUIT
PINRACE
WASHER
CLEARANCEPINCARRIER
PINIONSHAFT
PRESSFIT_OPTIONS
BEARING
TOOTH
RIM

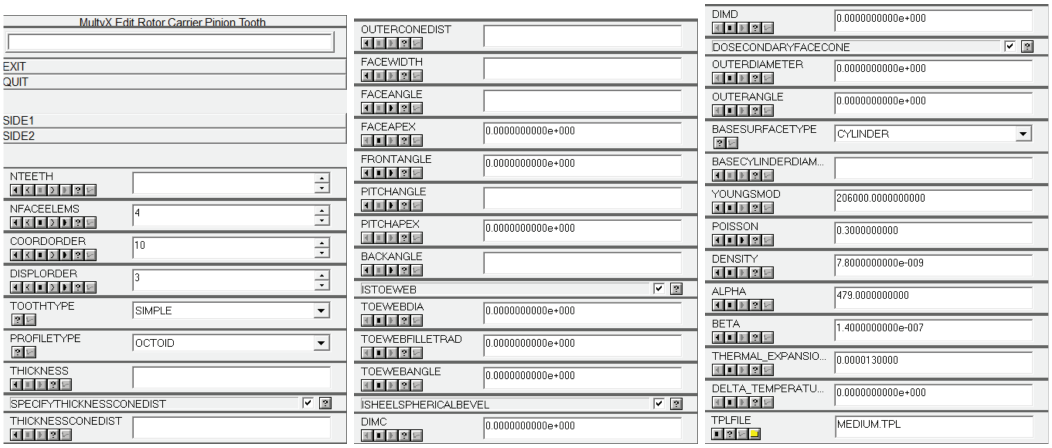
PINION 1
TYPE BEVEL
AXIALCONSTRAINT ☐
AXPOSN
PHIPOSN 90.0000000000
ENABLEWASHER ☑
ENABLE CLEARANCE PIN CARRIER ☑
THETAPOSN 0.0000000000e+000
TYPE_PINIONSHAFT COMPOUND
NPINIONSHAFTS 1
NBEARINGS 1
CIRCORDER 2
AXIALORDER 2
LUMPMASS 0.0000000000e+000
LUMPMOMINERTIA 0.0000000000e+000
LUMPALPHA 0.0000000000e+000

Figure 5.144 The bevel pinion menu.

5.9.2.1 The Bevel Pinion TOOTH Submenu The TOOTH menu for the simple bevel type pinions is shown in Figure 5.145. This menu is enabled by selecting TOOTHTYPE = SIMPLE and is identical to the TOOTH menu of the bevel gear on a rotor described in 5.6.1, except for the spherical heel option. Figure 5.146 shows the important blank dimensions of the simple bevel pinion.

The spherical heel is enabled by selecting the ISHEELSPHERICALBEVEL boolean checkbox. This enables the spherical heel parameter inputs HEELSPHERICALRADI, DIMC, & DIMD. HEELSHPERICALRADI sets the radius of the sphere. DIM D is the offset of the sphere center point in direction of the rotational axis and DIM C is the offset in the radial direction. The shpere radius is measured from the offset center point if DIM D and/or DIM C are non-zero.

Selecting TOOTHTYPE = WEBBED brings up the menu shown in Figure 5.147. The inputs for the webbed bevel pinion differ only in the parameters used to position the front and back surface planes. The back surface of the webbed bevel pinion is defined by the MOUNTINGDISTANCE and BACKANGLE, while the front surface is defined by the MOUNTINGDISTANCE, BEVELDEPTH, and FRONTANGLE. All other inputs are the remain identical as is shown in Figure 5.148.



NTEETH	
NFACEELEMS	4
COORDORDER	10
DISPLORDER	3
TOOTHTYPE	SIMPLE
PROFILETYPE	OCTOID
THICKNESS	
SPECIFYTHICKNESSCONEDIST	☑
THICKNESSCONEDIST	
OUTERCONEDIST	
FACEWIDTH	
FACEANGLE	
FACEAPEX	0.0000000000e+000
FRONTANGLE	0.0000000000e+000
PITCHANGLE	
PITCHAPEX	0.0000000000e+000
BACKANGLE	
ISTOEWEB	☑
TOEWEBDIA	0.0000000000e+000
TOEWEBFILLETRAD	0.0000000000e+000
TOEWEBANGLE	0.0000000000e+000
ISHEELSPHERICALBEVEL	☑
DIMC	0.0000000000e+000
DIMD	0.0000000000e+000
DOSECONDARYFACECONE	☑
OUTERDIAMETER	0.0000000000e+000
OUTERANGLE	0.0000000000e+000
BASESURFACETYPE	CYLINDER
BASECYLINDERDIAM...	
YOUNGSMOD	206000.0000000000
POISSON	0.3000000000
DENSITY	7.8000000000e-009
ALPHA	479.0000000000
BETA	1.4000000000e-007
THERMAL_EXPANSIO...	0.0000130000
DELTA_TEMPERATU...	0.0000000000e+000
TPLFILE	MEDIUM.TPL

Figure 5.145 The simple bevel pinion tooth menu.

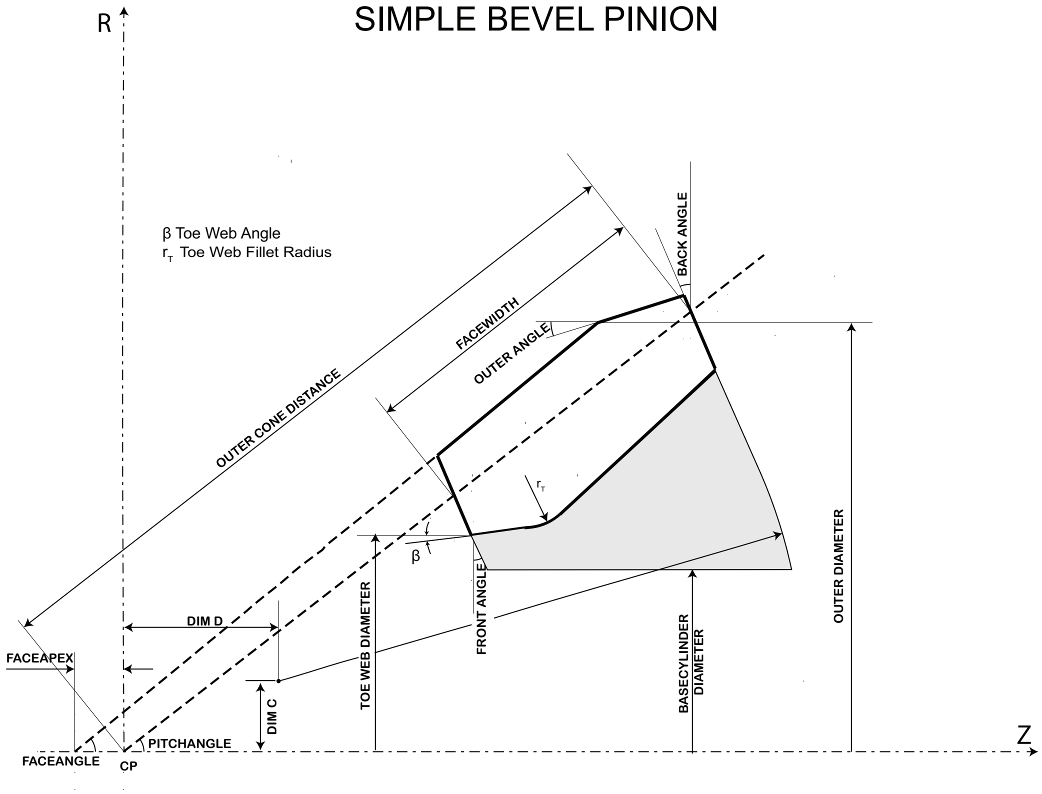
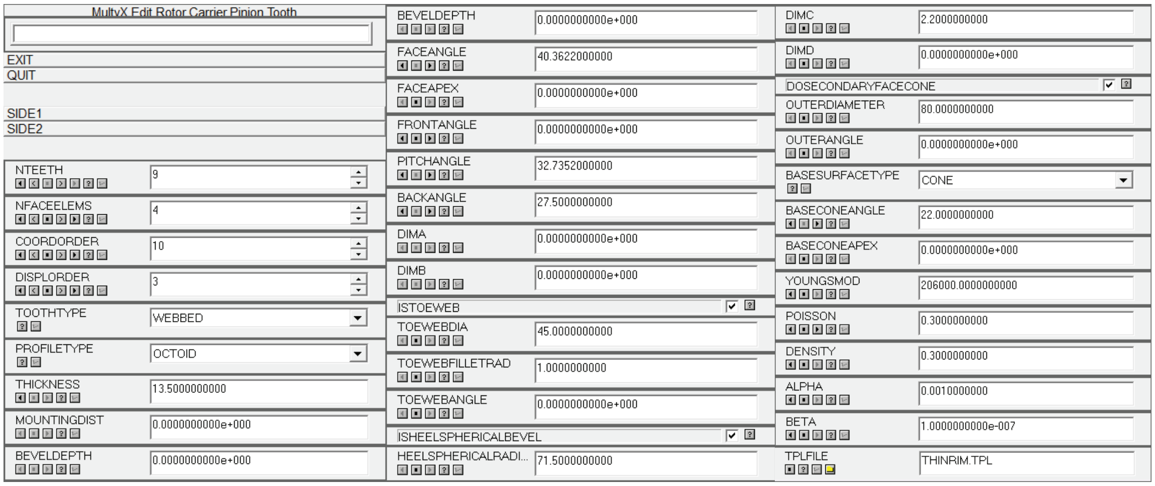

SIMPLE BEVEL PINION
R
Z
β Toe Web Angle
r_T Toe Web Fillet Radius
BACK ANGLE
FACEWIDTH
OUTER ANGLE
OUTER CONE DISTANCE
r_T
β
TOE WEB DIAMETER
FRONT ANGLE
BASECYLINDER DIAMETER
OUTER DIAMETER
DIM D
FACEAPEX
DIM C
PITCHANGLE
FACEANGLE
CP

Figure 5.146 The simple bevel pinion schematic.


MultyX Edit Rotor Carrier Pinion Tooth
EXIT
QUIT
SIDE1
SIDE2

NTEETH	9
NFACEELEMS	4
COORDORDER	10
DISPLORDER	3
TOOTHTYPE	WEBBED
PROFILETYPE	OCTOID
THICKNESS	13.5000000000
MOUNTINGDIST	0.0000000000e+000
BEVELDEPTH	0.0000000000e+000
BEVELDEPTH	0.0000000000e+000
FACEANGLE	40.3622000000
FACEAPEX	0.0000000000e+000
FRONTANGLE	0.0000000000e+000
PITCHANGLE	32.7352000000
BACKANGLE	27.5000000000
DIMA	0.0000000000e+000
DIMB	0.0000000000e+000
ISTOEWEB	☑
TOEWEBDIA	45.0000000000
TOEWEBFILLETRAD	1.0000000000
TOEWEBANGLE	0.0000000000e+000
ISHEELSPHERICALBEVEL	☑
HEELSPHERICALRADI...	71.5000000000
DIMC	2.2000000000
DIMD	0.0000000000e+000
DOSECONDARYFACECONE	☑
OUTERDIAMETER	80.0000000000
OUTERANGLE	0.0000000000e+000
BASESURFACETYPE	CONE
BASECONEANGLE	22.0000000000
BASECONEAPEX	0.0000000000e+000
YOUNGSMOD	206000.0000000000
POISSON	0.3000000000
DENSITY	0.3000000000
ALPHA	0.0010000000
BETA	1.0000000000e-007
TPLFILE	THINRIM.TPL

Figure 5.147 The webbed bevel pinion tooth menu.

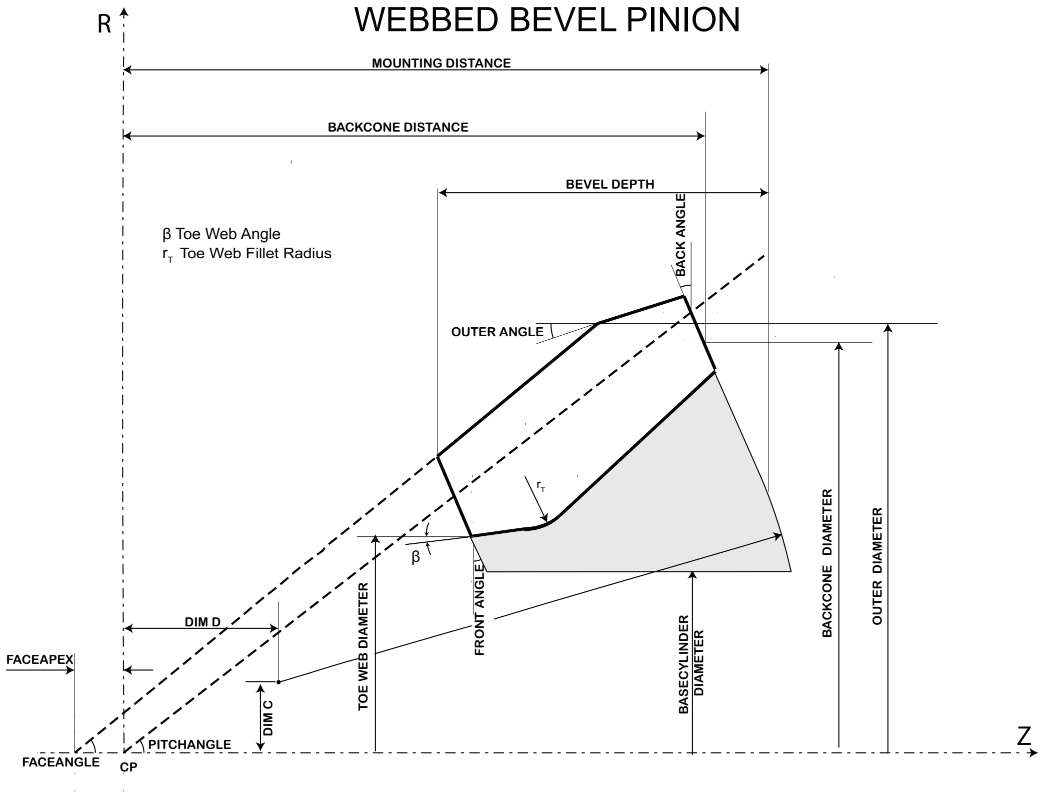
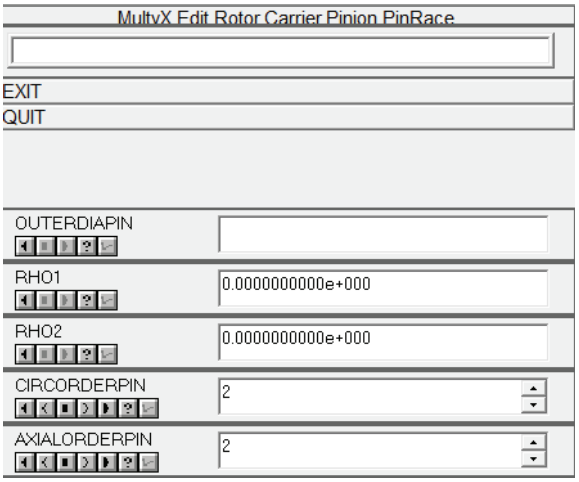

WEBBED BEVEL PINION
R
MOUNTING DISTANCE
BACKCONE DISTANCE
BEVEL DEPTH
β Toe Web Angle
r_T Toe Web Fillet Radius
BACK ANGLE
OUTER ANGLE
r_T
β
TOE WEB DIAMETER
FRONT ANGLE
BASECYLINDER DIAMETER
BACKCONE DIAMETER
OUTER DIAMETER
DIM D
FACEAPEX
DIM C
PITCHANGLE
FACEANGLE
CP
Z

Figure 5.148 The webbed bevel pinion schematic.

5.9.2.2 The Bevel Pinion PINRACE Submenu The PINRACE submenu, shown in Figure 5.149, is used to define the race surface on the bevel pinion pin shaft. RHO1 and RHO2 define the spherical radii to the toe and heel side of the race, respectively. OUTERDIAPIN defines the diameter of the pin at which the race surface is to be defined. If a bearing is modeled, the bearing inner race surface diameter will be identical to OUTERDIAPIN.

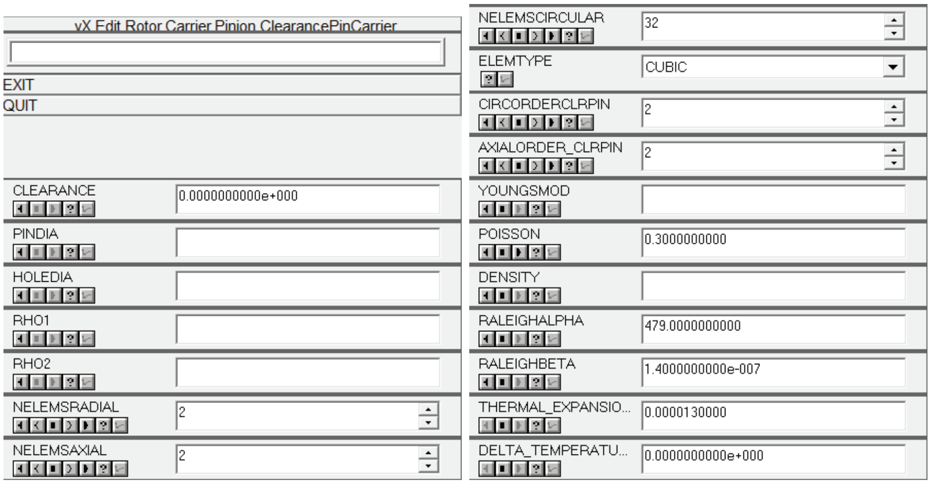

MultyX Edit Rotor Carrier Pinion PinRace

EXIT
QUIT

OUTERDIAPIN	
RHO1	0.0000000000e+000
RHO2	0.0000000000e+000
CIRCORDERPIN	2
AXIALORDERPIN	2

Figure 5.149 The bevel pinion PINRACE menu.

5.9.2.3 The Bevel Pinion CLEARANCE PIN CARRIER Submenu Figure 5.150 shows the CLEARANCEPINCARRIER submenu, which becomes active when the ENABLE CLEARANCE PIN CARRIER option is selected. This option allows the user to model contact between the carrier pin and the pin hole by adding a small amount of material to the inside of the hole and the outside of the pin. Material may need to be removed from the pin, carrier hole, or both components so that there is a diametral gap $>= 0.4$ * pin diameter to accomodate the added material. PINDIA and HOLEDIA are the diameters of the pin and hole, respectively. The front and back axial positions of the surfaces are given by the RHO1 and RHO2 inputs. The finite element mesh size, interface orders, and material properties are defined in this menu in a similar manner as the shaft segment menu.


vX Edit Rotor Carrier Pinion ClearancePinCarrier

EXIT
QUIT

CLEARANCE	0.0000000000e+000
PINDIA	
HOLEDIA	
RHO1	
RHO2	
NELEMSRADIAL	2
NELEMSAXIAL	2
NELEMSCIRCULAR	32
ELEMTYPE	CUBIC
CIRCORDERCLRPIN	2
AXIALORDER_CLRPIN	2
YOUNGSMOD	
POISSON	0.3000000000
DENSITY	
RALEIGHALPHA	479.0000000000
RALEIGHBETA	1.4000000000e-007
THERMAL_EXPANSIO...	0.0000130000
DELTA_TEMPERATU...	0.0000000000e+000

Figure 5.150 The CLEARANCEPINCARRIER menu.

5.9.2.4 The Bevel Pinion PINIONSHAFT and BEARING The PINIONSHAFT menu is used to model a pinion shaft between the pinion bearing outer race and the pinion rim inner race surface. This shaft is modeled in an identical manner to the rotor shafts described previously. Refer to the rotor shaft section for details on the PINIONSHAFT and SEGMENT menus.

The BEARING MENU is similar to the CONNECTORS menu described in the Connectors section. Refer to this section for a description of the BEARING menu inputs.

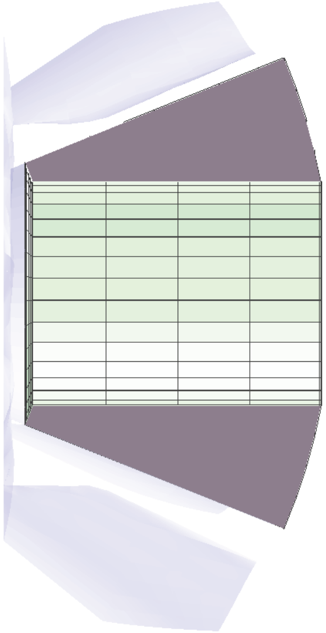


Figure 5.151 The Spherical type rim.

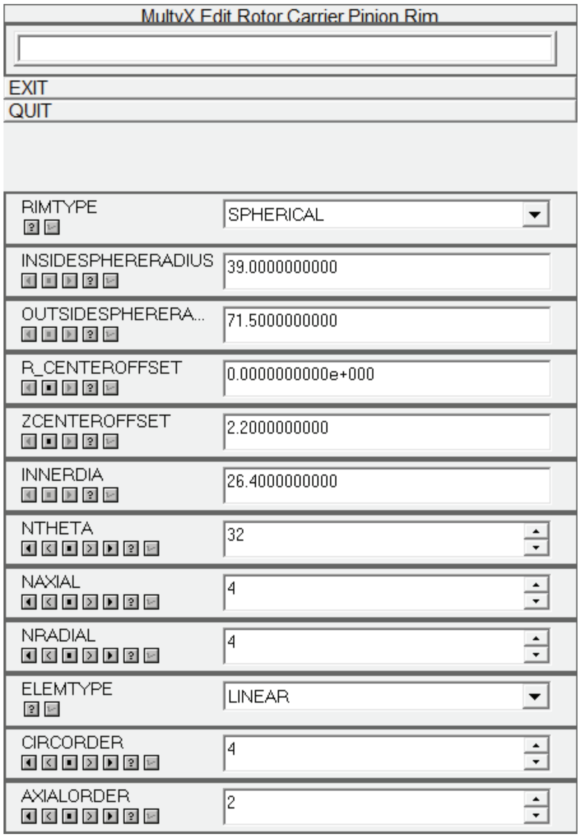
5.9.2.5 The RIM and WASHER for Bevel Pinions Figure 5.151 shows the spherical pinion rim model. The spherical rim menu shown in Figure 5.152 is accessed by clicking the RIM button in the PINION menu and selecting RIMTYPE = SPHERICAL. The sphere center point is located at the bevel pinion crossing point by default. The axial and radial position of the sphere center can be shifted by specifying the R_CENTEROFFSET and/or ZCENTEROFFSET parameters. The INSIDESPHERERADIUS and OUTSIDESPHERERADIUS are defined from the offset center point.

5.9.3 Pinion groups

As the name suggests a group of pinions consists of a number of pinions each pinion may in turn have a number of decks. A group of such pinions is placed on the carrier at a particular angle with respect to the carrier axis. A carrier can be said to consist of a number of such groups. All these groups (mounted on the same carrier) are similar in all respects except for the location of the group on the carrier. Each group has one copy of each pinion type. Since each group has a number of pinions and each pinion has a number of decks, a very complicated model of the carrier can be built using the *Transmission3D* package.

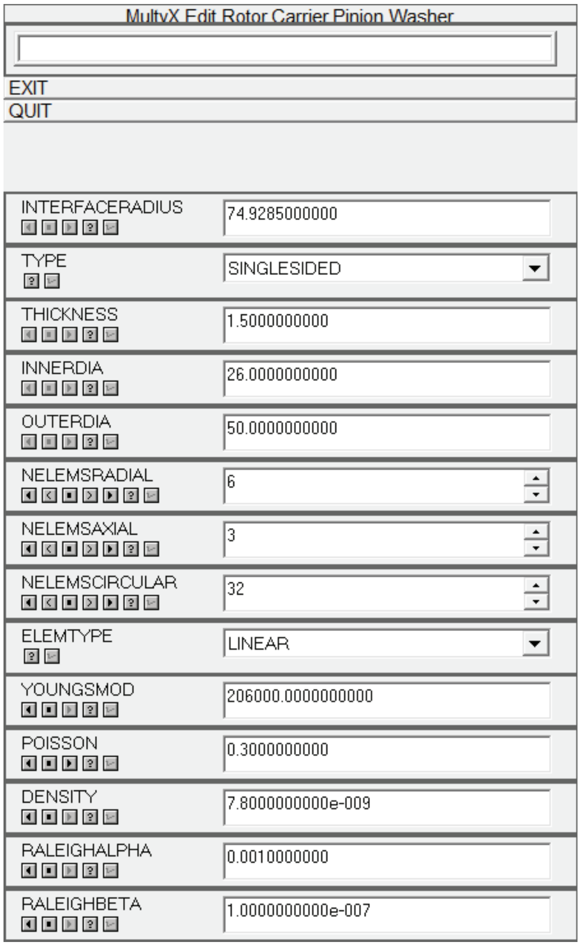
The GROUP command in Figure 5.112 leads to the group menu shown in Figure 5.154. The number of groups is specified in the NGROUPS menu. An individual group may be selected by the GROUP item. The axial shift of the pinion group with respect to the carrier is specified by AXPOSN. A value of 0.0 will leave each deck of pinion at the position AXPOSNPOSN requested in the Deck Tooth menu (Figure **??**). A non-zero value will shift the decks by that amount. THETA defines the angular position of the pinion group in degrees. If this value is 0.0, each pinion in the group will be at its nominal angular position specified by THETAPOSN in the Pinion menu (Figures **??** and **??**). Otherwise the angular position of each pinion will be advanced by this angular amount in degrees, following the right hand rule about the carrier Z-axis.

Figures 5.155 and 5.156 show two pinions with 2 and 3 groups respectively.


MultyX Edit Rotor Carrier Pinion Rim
EXIT
QUIT

RIMTYPE	SPHERICAL
INSIDESPHERERADIUS	39.0000000000
OUTSIDESPHERERA...	71.5000000000
R_CENTEROFFSET	0.0000000000e+000
ZCENTEROFFSET	2.2000000000
INNERDIA	26.4000000000
NTHETA	32
NAXIAL	4
NRADIAL	4
ELEMTYPE	LINEAR
CIRCORDER	4
AXIALORDER	2

Figure 5.152 The Spherical type rim menu.



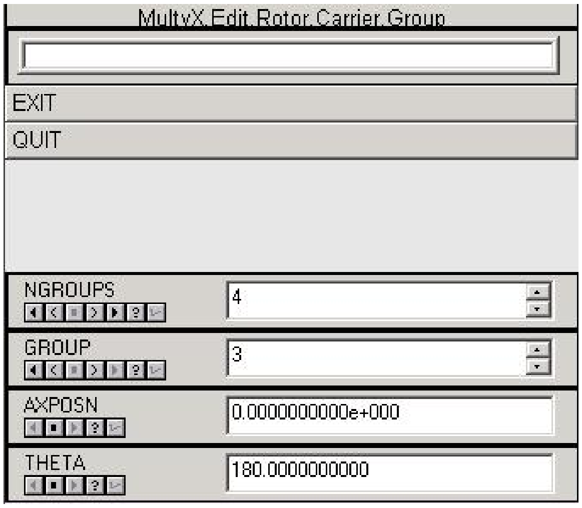
MultyX Edit Rotor Carrier Pinion Washer

EXIT

QUIT

INTERFACERADIUS	74.9285000000
TYPE	SINGLESIDED
THICKNESS	1.5000000000
INNERDIA	26.0000000000
OUTERDIA	50.0000000000
NELEMSRADIAL	6
NELEMSAXIAL	3
NELEMSCIRCULAR	32
ELEMTYPE	LINEAR
YOUNGSMOD	206000.0000000000
POISSON	0.3000000000
DENSITY	7.8000000000e-009
RALEIGHALPHA	0.0010000000
RALEIGHBETA	1.0000000000e-007

Figure 5.153 The spherical washer menu.


MultyX.Edit.Rotor.Carrier.Group
EXIT
QUIT

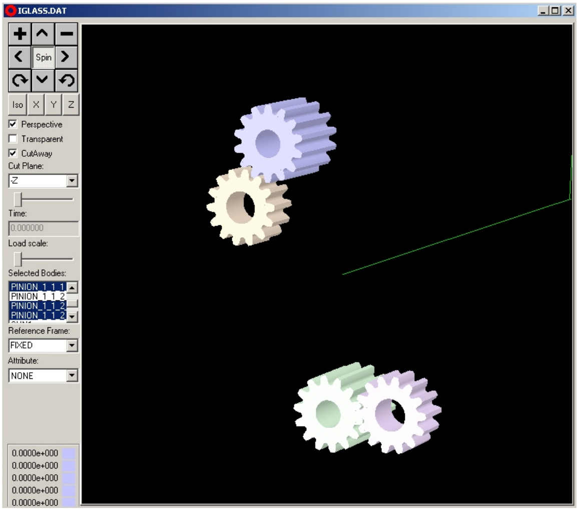
NGROUPS 4

GROUP 3

AXPOSN 0.0000000000e+000

THETA 180.0000000000

Figure 5.154 The menu for specifying the group data.


IGLASS.DAT
Spin
Iso
X
Y
Z

☑ Perspective
☐ Transparent
☑ CutAway

Cut Plane: -Z

Time: 0.000000

Load scale:

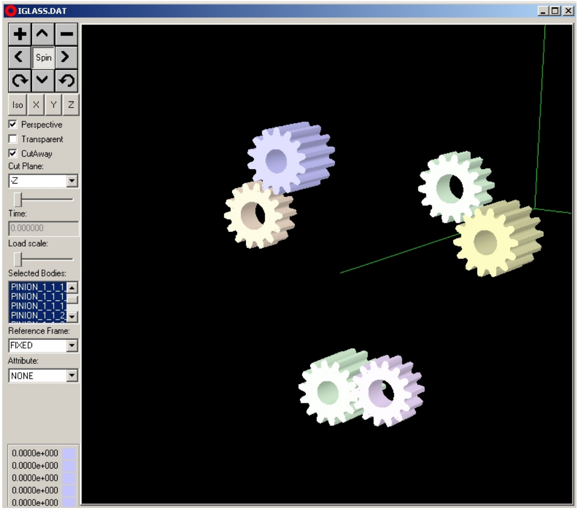
Selected Bodies:
PINION_1_1_1
PINION_1_1_2
PINION_1_1_2
PINION_1_1_2

Reference Frame: FIXED

Attribute: NONE

0.0000e+000
0.0000e+000
0.0000e+000
0.0000e+000
0.0000e+000

Figure 5.155 Two pinions with 2 groups.



☑ Perspective
☐ Transparent
☑ CutAway
Cut Plane: -Z
Time: 0.000000
Load scale:
Selected Bodies:
PINION_1_1_1
PINION_1_1_1
PINION_1_1_1
PINION_1_1_2
Reference Frame: FIXED
Attribute: NONE

0.0000e+000
0.0000e+000
0.0000e+000
0.0000e+000
0.0000e+000

Figure 5.156 Two pinions with 3 groups.

5.9.4 Permissible Angular Locations of Pinion Groups

5.9.4.1 Simple planetary system In a simple planetary system with a sun and a ring gear, we can always orient the sun and the ring gear so that the first pinion can be assembled as shown in Figure 5.157. With this pinion in place, there are only a few specific angular locations where it is possible to place the other pinions. Let Φ denote one of the angular positions where it is possible to place another pinion.

If we hold the ring gear fixed and rotate the sun and carrier, by angles θ_s and θ_c (θ_c = Φ) respectively, so that $Pinion1$ moves to the location occupied by $Pinion2$, then the teeth of the sun gear in the new position should coincide with the teeth of the sun gear in its original position.

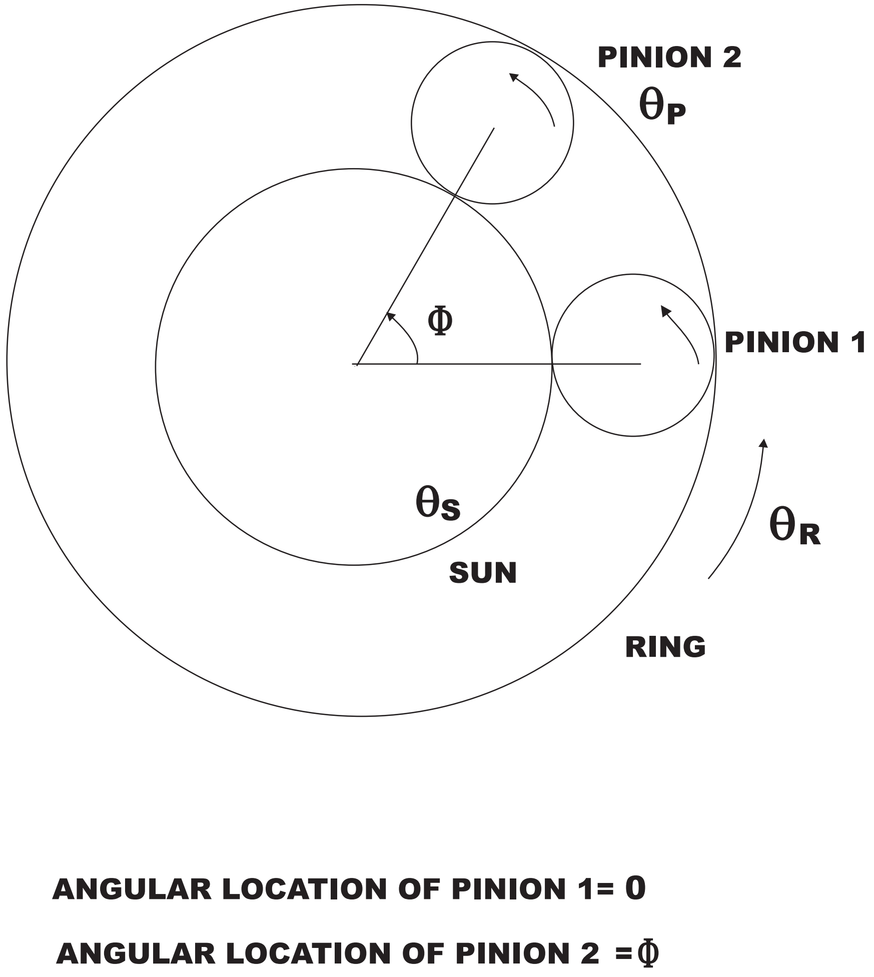

PINION 2
θP
Φ
PINION 1
θS
SUN
θR
RING
ANGULAR LOCATION OF PINION 1= 0
ANGULAR LOCATION OF PINION 2 =Φ

Figure 5.157 The angular position of pinions in a planetary system.

In other words, the sun gear rotaion θ_s should be an integer multiple of its angular pitch $2\pi/N_s$, i.e, $\theta_s = n(2\pi/N_s)$. Here n can be any integer.

The rotations of the sun, pinion, carrier and ring are related by

$$(\theta_s - \theta_c)N_s = -(\theta_p - \theta_c)N_p = -(\theta_R - \theta_c)N_R \tag{5.1}$$

Since the ring gear is fixed, θ_R = 0. Hence,

$$(\theta_s - \theta_c)N_s = -(\theta_p - \theta_c)N_p = \theta_c N_R$$

We need to determine the value of Φ for which if θ_c = Φ and θ_s = $n(2\pi/N_s)$, for any integer n. Therefore,

$$\begin{aligned}(\theta_s - \theta_c)N_s &= \theta_c N_R \\ \theta_s &= \theta_c.(N_s + N_R)/N_s \\ 2n\pi/N_s &= \Phi.(N_s + N_R)/N_s\end{aligned}$$

Hence,

$$\Phi = \frac{2n\pi}{(N_s + N_R)} \tag{5.2}$$

5.9.4.2 One pinion with two decks For the example of a pinion with two decks (Figure 5.158), one of which contacts the sun, and the other the ring,

$$(\theta_s - \theta_c)N_s = -(\theta_p - \theta_c)N_{p_1} \tag{5.3}$$

$$(\theta_p - \theta_c)N_{p_2} = (\theta_R - \theta_c)N_R \tag{5.4}$$

Set θ_R = 0, then

$$(\theta_p - \theta_c) = -\theta_c.N_R/N_{p_2}$$

Substituting for (θ_p - θ_c)

$$(\theta_s - \theta_c)N_s = \theta_c.N_R.N_{p_1}/N_{p_2}$$

Set θ_c = Φ and θ_s = $2n\pi/N_s$. Hence,

$$\Phi = \frac{2n\pi.N_s.N_{p_2}}{N_s.N_{p_2} + N_R.N_{p_1}}, \tag{5.5}$$

where n = 1,2, ...are allowable locations of the pinion groups

.

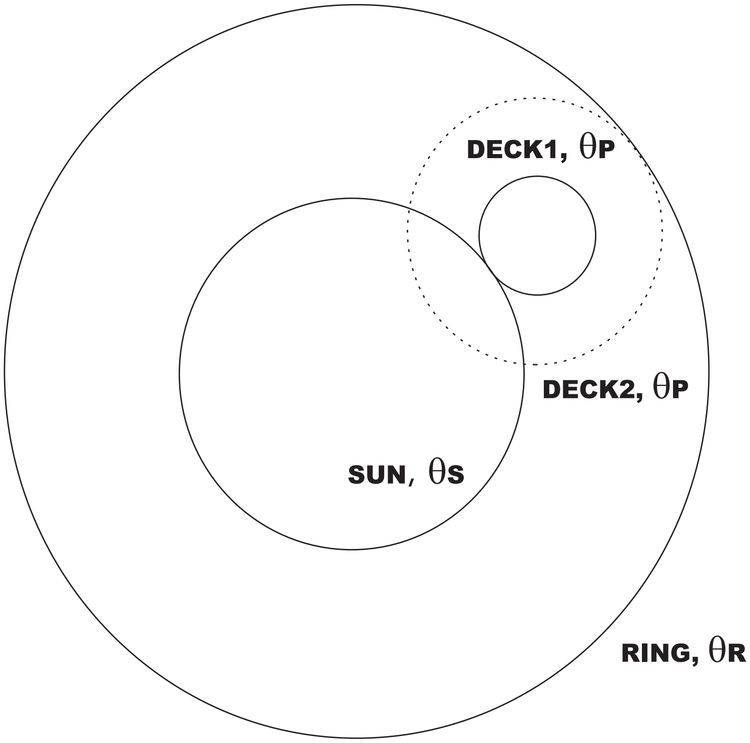

DECK1, θP
DECK2, θP
SUN, θS
RING, θR

Figure 5.158 One pinion with two decks.

5.9.4.3 Two pinions with one deck In this case (Figure 5.159),

$$(\theta_s - \theta_c)N_s = -(\theta_{p_1} - \theta_c)N_{p_1} = (\theta_{p_2} - \theta_c)N_{p_2} = (\theta_R - \theta_c)N_R$$
$$(\theta_s - \theta_c)N_s = (\theta_R - \theta_c)N_R$$

Hence,

$$\Phi = \frac{2n\pi}{(N_R - N_s)} \tag{5.6}$$

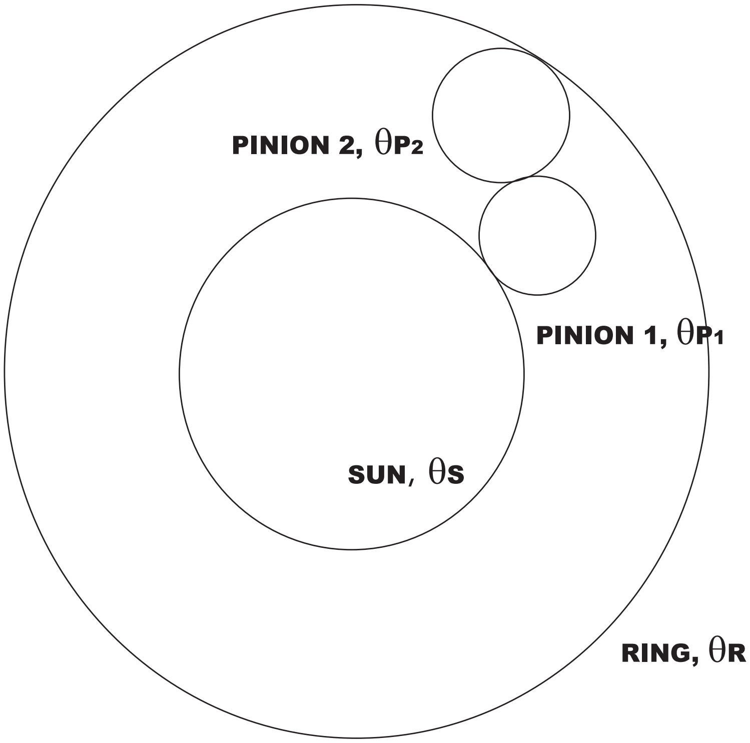

PINION 2, θP2
PINION 1, θP1
SUN, θS
RING, θR

Figure 5.159 Two pinions with one deck.

CHAPTER 6

CONNECTORS

If the ENABLECONNECTORS menu is turned on in the EDIT menu then the CONNECTOR command pops up as shown in Figure 6.1. The CONNECTOR command leads to the connector menu as shown in Figure 6.2. A connector is used to connect two rotors, a rotor to ground, or a pinion to a carrier. A connector can be a bearing or a spline. The available connector types are STIFFNESS, INTERNALSPLINED, EXTERNALSPLINED, ROLLERS, JOURNAL, TRIPOD, THRUSTROLLER, and THRUSTSTIFFNESS.

6.1 Stiffness bearings

The default type of connector is the stiffness type bearing. For a stiffness type bearing the bearing is treated as a stiffness connection between the two bearing races (Figure 6.3). Each race has an attached reference frame. The race is treated as a rigid body, and the six degrees of freedom of the first bearing race and the six degrees of freedom of the second bearing race are interrelated through a stiffness matrix.

The six degrees of freedom are the three translation degrees of freedom U_x, U_y and U_z, and three rotation degrees of freedom θ_x, $\theta_y$and and θ_z (Figure 6.4). The degrees of freedom represent the motion of race 1 relative to race 2. The components are measured in the reference frame attached to race 2.

The bearing may also generate internal reaction forces and moments. The six components of bearing reaction consist of three forces F_x, F_y and F_z, and the three moments M_x, M_y and M_z (Figure 6.5). Again, these reactions are those exerted by race 1 on race 2. The components are computed in the reference frame of race 2.

The stiffness type bearing menu is shown in Figure 6.2. Table 6.1 shows the terms used in the stiffness bearing menu. You can specify a unique name for the connector in the NAME item. The location of the bearing origin is at XPOS, YPOS and ZPOS, and the orientation of its axis is specified through AX, AY and AZ. Torsional stiffness and bending stiffness apply to rotation about this origin.

As shown in Figure 6.6, the axial extent of race1 is [AXPOSN1RACE1,AXPOSN2RACE1] and the axial extent of race 2 is given by [AXPOSN1RACE2,AXPOSN2RACE2]. Usually the bearing origin lies at the middle of the two race extents, but this need not always be the case. The diameters for race 1 and race 2

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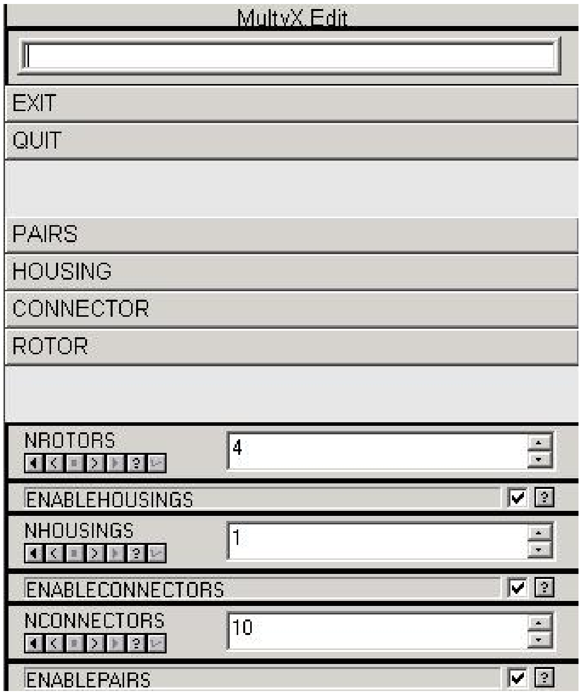


NROTORS 4

ENABLEHOUSINGS ☑

NHOUSINGS 1

ENABLECONNECTORS ☑

NCONNECTORS 10

ENABLEPAIRS ☑

Figure 6.1 The edit menu with the connector command.

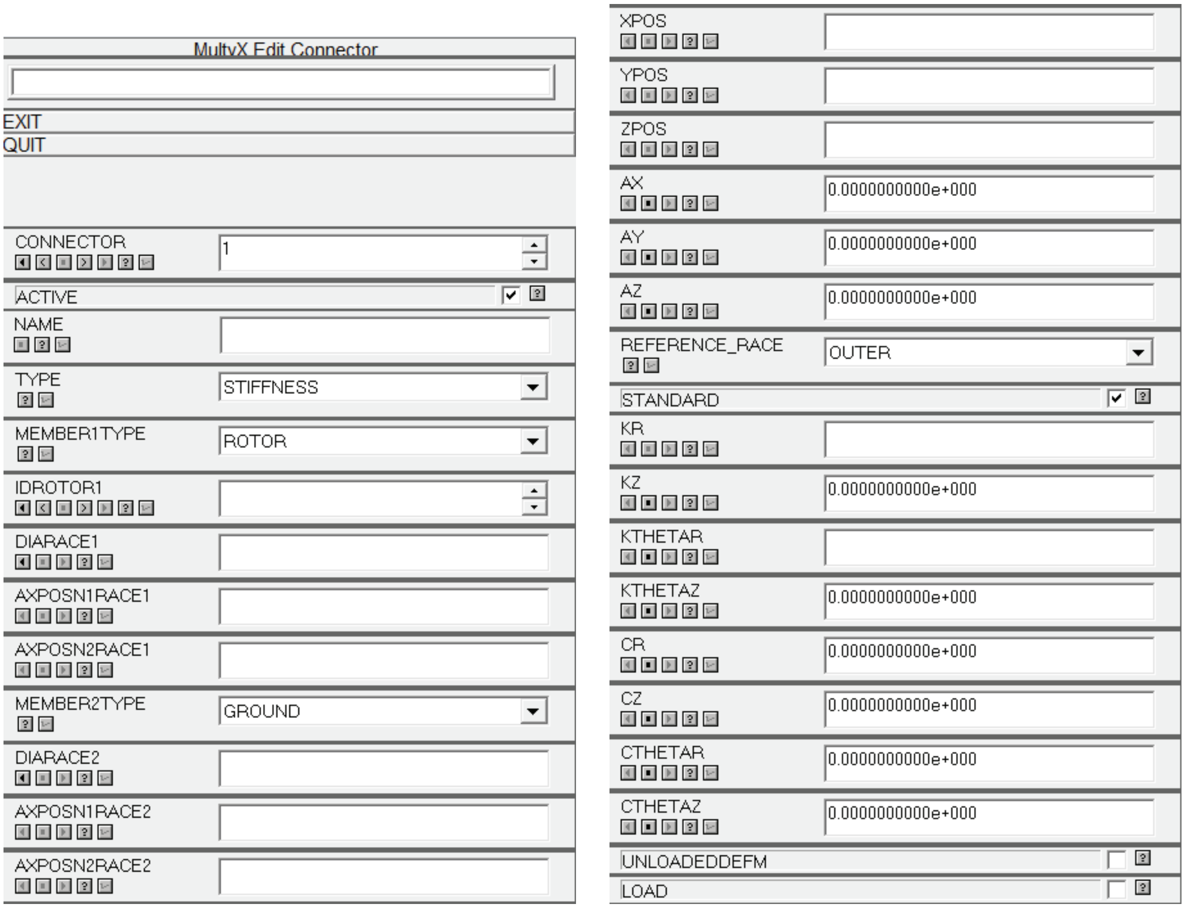
are given by DIARACE1 and DIARACE2 menus. The race diameters the axial extentS of the race are used to mate the bearing race with a race on the rotor. The diameter of the bearing race must match exactly with the diameter of the mating race on the rotor. The axial extent of the bearing race must overlap with the axial extent of the mating race.

The radial, axial, bending and torsional stiffness values are specified in KR, KZ, KTHETAR and KTHETAZ. Corresponding damping terms are specified in CR, CZ, CTHETAR and CTHETAZ. If the unloaded deformation option UNLOADEDDEFM is turned on then it is possible to specify a deformation [UX, UY, UZ, THETAX, THETAY, THETAZ] for the unloaded state of the bearing. Table 6.2 describes the additional items in the stiffness bearing menu exposed when UNLOADEDDEFM is turned on. If the LOAD option is turned on then it is possible to specify an additional load [FX, FY, FZ, MX, MY, MZ] at the bearing. Table 6.3 describes the additional items exposed in the stiffnes bearing menu when the LOAD option is turned on. The additional items are also shown in Figure 6.7. The deformation and the load components are measured in the race2 reference frame.

A bearing is meant to connect two members in the model. The first member is selected in MEMBER1TYPE. MEMBER1TYPE may be HOUSING, ROTOR or PINION. MEMBER2TYPE selects the second member, If MEMBER1TYPE is PINION (Figure 6.8), then it is understood that the second member is the carrier, and MEMBER2TYPE is not exposed. Otherwise MEMBER2TYPE is exposed, and it may be GROUND, HOUSING or ROTOR.

When MEMBER1TYPE is PINION, the bearing is positioned using the AXIALPOSN item. This is the axial position of the bearing with respect to the rotor origin and rotor axis or the rotor on which the pinion is mounted.

Table 6.4 describes the bearing menu specific to the Pinion member type.



MultyX Edit Connector

EXIT

QUIT

CONNECTOR	1
ACTIVE	☑
NAME	
TYPE	STIFFNESS
MEMBER1TYPE	ROTOR
IDROTOR1	
DIARACE1	
AXPOSN1RACE1	
AXPOSN2RACE1	
MEMBER2TYPE	GROUND
DIARACE2	
AXPOSN1RACE2	
AXPOSN2RACE2	

XPOS	
YPOS	
ZPOS	
AX	0.0000000000e+000
AY	0.0000000000e+000
AZ	0.0000000000e+000
REFERENCE_RACE	OUTER
STANDARD	☑
KR	
KZ	0.0000000000e+000
KTHETAR	
KTHETAZ	0.0000000000e+000
CR	0.0000000000e+000
CZ	0.0000000000e+000
CTHETAR	0.0000000000e+000
CTHETAZ	0.0000000000e+000
UNLOADEDDEFM	☐
LOAD	☐

Figure 6.2 The menu for a stiffness type connector

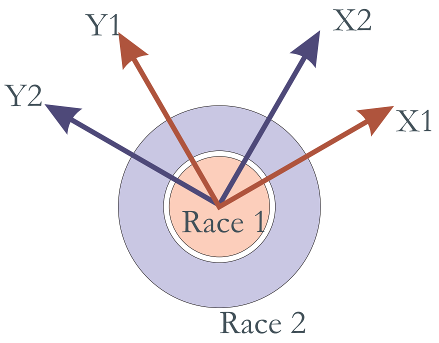


Figure 6.3 Bearing races

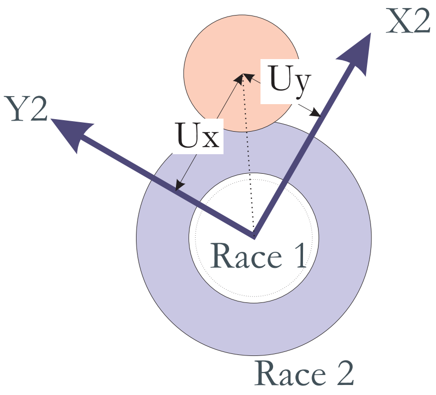

X2
Y2
Uy
Ux
Race 1
Race 2

Figure 6.4 Bearing deformation

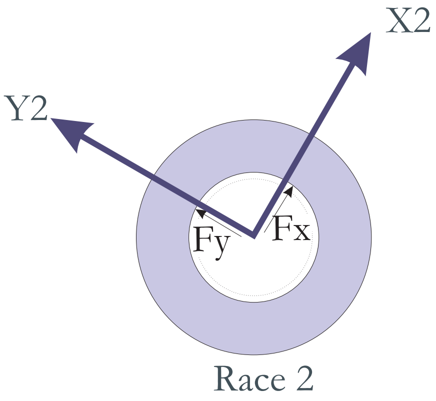

X2
Y2
Fy
Fx
Race 2

Figure 6.5 Bearing reaction

Table 6.1 The stiffness type bearing menu

Item	Description
NCONNECTORS	Integer, Number of connectors in the system
CONNECTOR	Integer, Connector number
ACTIVE	Boolean, Turns the connector on and off
NAME	String, Name of the bearing
XPOS	Float, X coordinate of the bearing
YPOS	Float, Y coordinate of the bearing
ZPOS	Float, Z coordinate of the bearing
AX	Float, X component of the axis of the bearing
AY	Float, Y component of the axis of the bearing
AZ	Float, Z component of the axis of the bearing
TYPE	Switch, Bearing type
KR	Float, Radial stiffness of the bearing
KZ	Float, Axial stiffness of the bearing
KTHETAR	Float, Bending stiffness of the bearing
KTHETAZ	Float, Torsional stiffness of the bearing
CR	Float, Radial damping of the bearing
CZ	Float, Axial damping of the bearing
CTHETAR	Float, Bending damping of the bearing
CTHETAZ	Float, Torsional damping of the bearing
UNLOADEDDEFM	Boolean, Whether to enable unloaded defm. of the bearing
LOAD	Boolean, Whether to enable an additional bearing load
MEMBER1TYPE	Switch, Member1 type
IDROTOR1	Integer, Rotor ID
DIARACE1	Float, Diameter of race 1 of the bearing
AXPOSN1RACE1	Float, Axial coordinate of race 1
AXPOSN2RACE1	Float, Axial coordiante of race 1
MEMBER2TYPE	Switch, Member2 type
IDROTOR2	Integer, Rotor ID (If MEMBER2TYPE = ROTOR)
DIARACE2	Float, Diameter of race 2 of the bearing
AXPOSN1RACE2	Float, Axial coordinate of race 2
AXPOSN2RACE2	Float, Axial coordiante of race 2

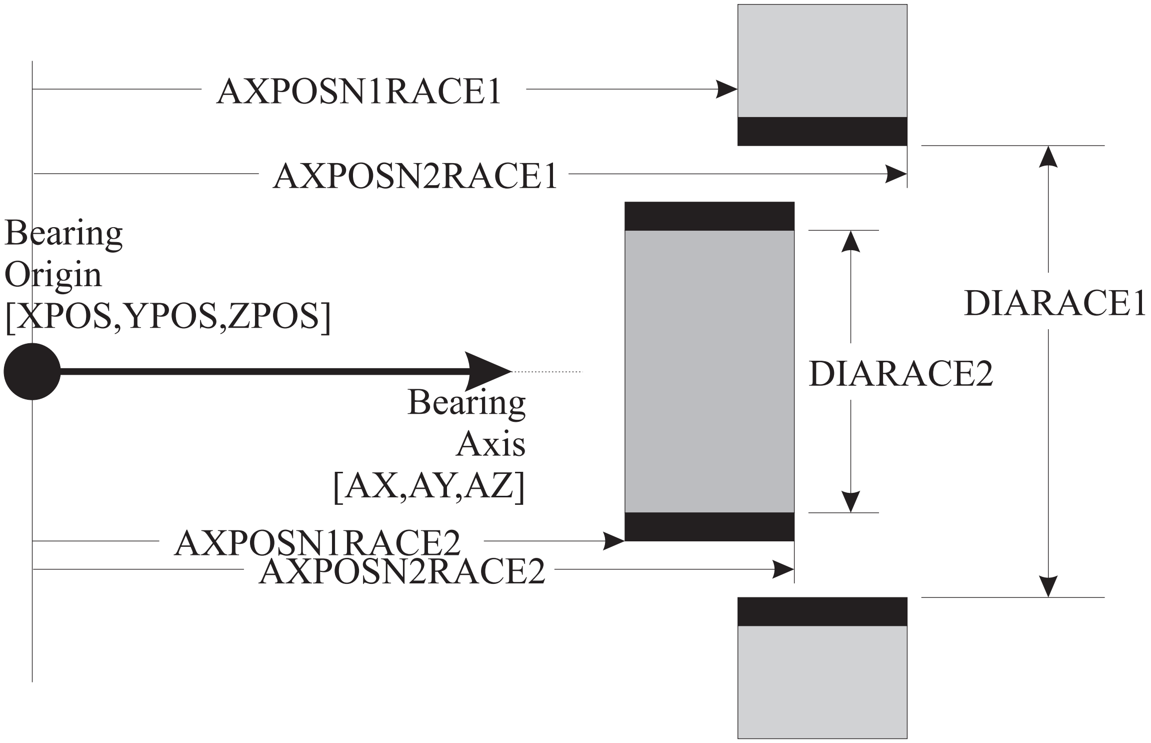

AXPOSN1RACE1
AXPOSN2RACE1
Bearing
Origin
[XPOS,YPOS,ZPOS]
Bearing
Axis
[AX,AY,AZ]
AXPOSN1RACE2
AXPOSN2RACE2
DIARACE1
DIARACE2

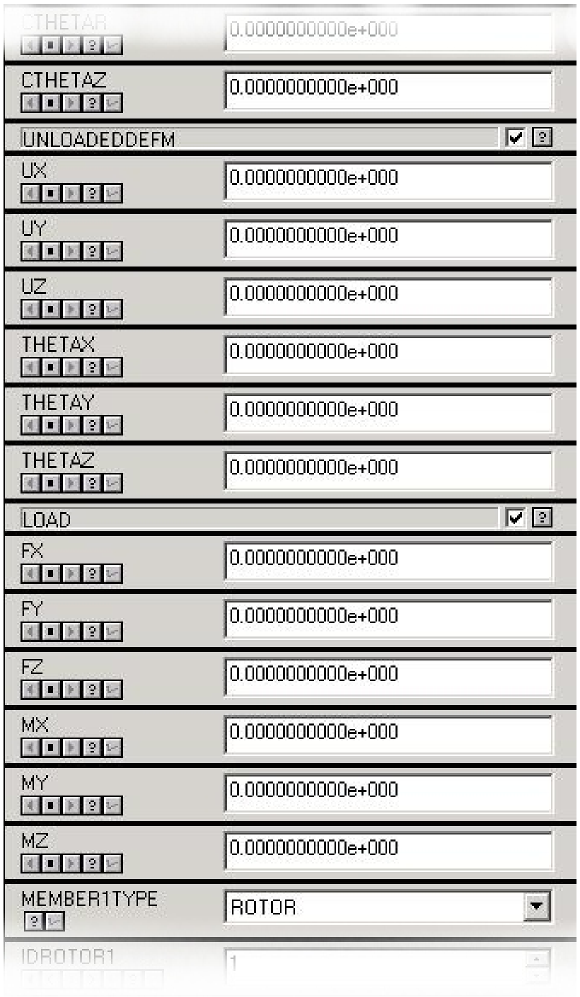
Figure 6.6 Bearing race dimensions

Table 6.2 Stiffness bearing menu specific to the UNLOADEDDEFM option being turned on

Item	Description
UX	Float, Unloaded deformation U_x component of bearing
UY	Float, Unloaded deformation U_y component of bearing
UZ	Float, Unloaded deformation U_z component of bearing
THETAX	Float, Unloaded deformation θ_x component of bearing
THETAY	Float, Unloaded deformation θ_y component of bearing
THETAZ	Float, Unloaded deformation θ_z component of bearing

Table 6.3 Stiffness bearing menu specific to the LOAD option being turned on

Item	Description
FX	Float, Load component F_x at the bearing
FY	Float, Load component F_y at the bearing
FZ	Float, Load component F_z at the bearing
MX	Float, Load component M_x at the bearing
MY	Float, Load component M_y at the bearing
MZ	Float, Load component M_z at the bearing



CTHETAR 0.0000000000e+000

CTHETAZ 0.0000000000e+000

UNLOADEDDEFM ☑

UX 0.0000000000e+000

UY 0.0000000000e+000

UZ 0.0000000000e+000

THETAX 0.0000000000e+000

THETAY 0.0000000000e+000

THETAZ 0.0000000000e+000

LOAD ☑

FX 0.0000000000e+000

FY 0.0000000000e+000

FZ 0.0000000000e+000

MX 0.0000000000e+000

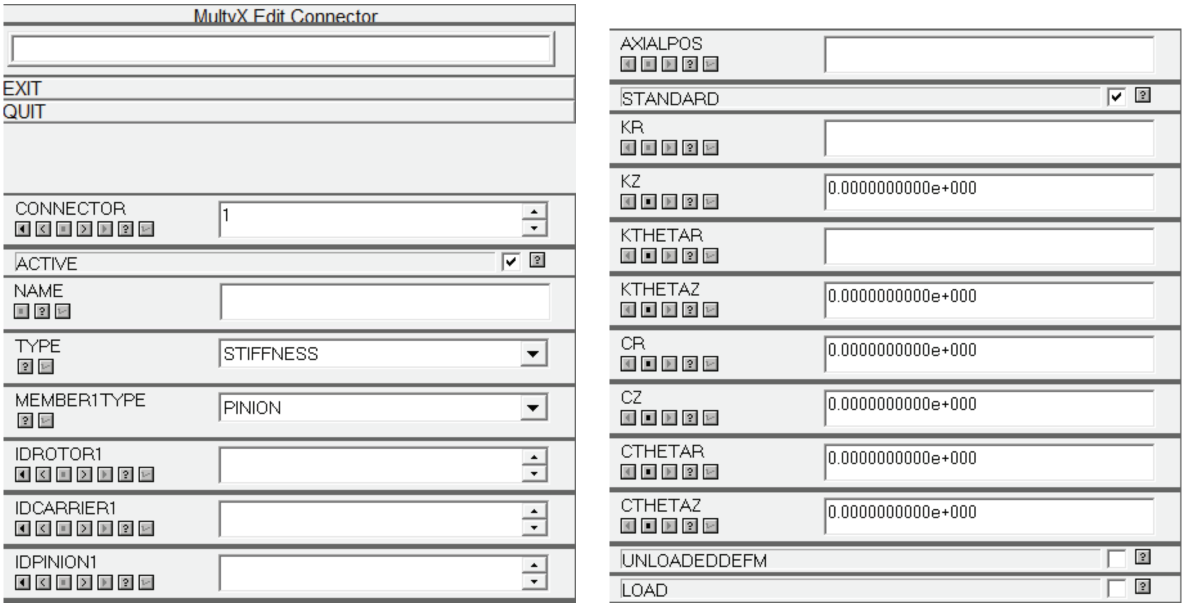
MY 0.0000000000e+000

MZ 0.0000000000e+000

MEMBER1TYPE ROTOR

IDROTOR1 1

Figure 6.7 The additional menu items for a stiffness bearing with the unloaded deformation and load option turned on



CONNECTOR 1

ACTIVE ☑

NAME

TYPE STIFFNESS

MEMBER1TYPE PINION

IDROTOR1

IDCARRIER1

IDPINION1

AXIALPOS

STANDARD ☑

KR

KZ 0.0000000000e+000

KTHETAR

KTHETAZ 0.0000000000e+000

CR 0.0000000000e+000

CZ 0.0000000000e+000

CTHETAR 0.0000000000e+000

CTHETAZ 0.0000000000e+000

UNLOADEDDEFM ☐

LOAD ☐

Figure 6.8 The menu for a stiffness type connector when MEMBER1TYPE is PINION

Table 6.4 Stiffness bearing menu specific to Pinion member type

Item	Description
AXIALPOS	Float, Axial position of the bearing with respect to the rotor origin and axis.
IDROTOR	Integer, Rotor ID
IDCARRIER	Integer, Carrier ID
IDPINION	Integer, Pinion ID

Table 6.5 CONTACT_GRID Menu for Roller Bearing Connectors

Item	Description
SEPTOL	Float, Controls maximum separation between mating surfaces. Surfaces separated by more than this distance will not be considered in the contact analysis.
NPROFDIVS	Integer, Variable controls the number of contact patches or cells that will be used to cover the contact zone between gear teeth
DSPROF	Float, Controls the width of the contact zone in physical length units.
NFACEDIVS	Integer, Controls the number of contact patches or cells that will be used along the length of the contact zone.

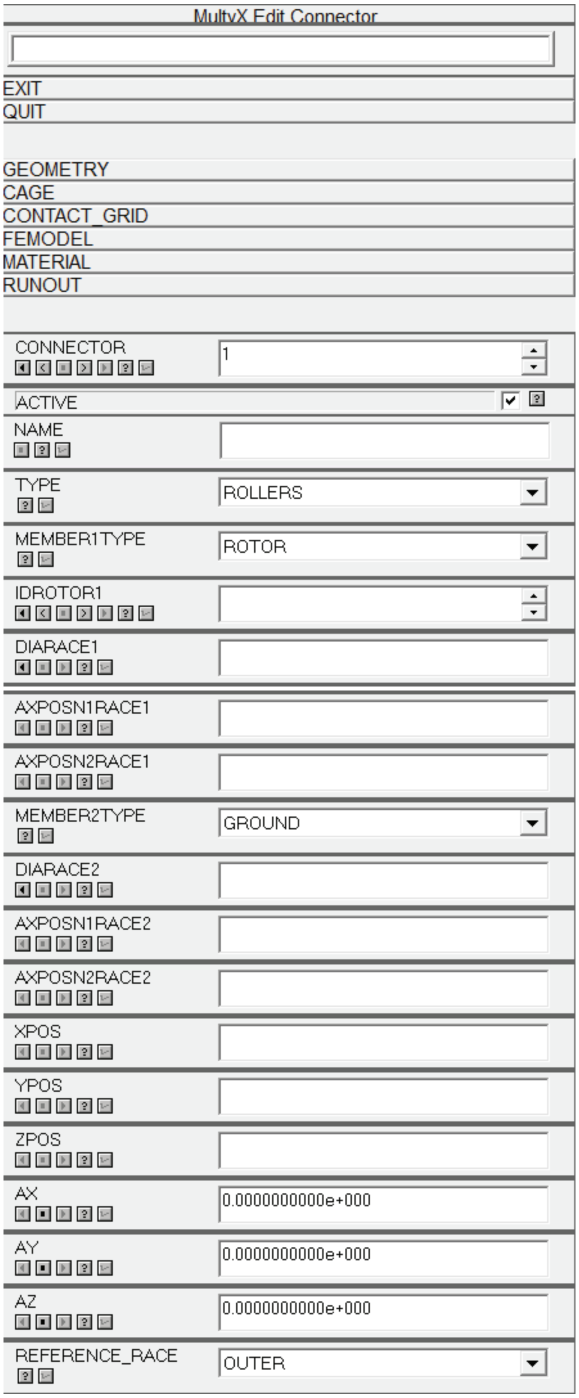
6.2 Roller bearings

A ROLLER bearing can be selected in the TYPE item, as shown in the CONNECTOR menu in Figure 6.9. The connector can be disabled/enabled, similarly to other connectors and contact pairs by disabling/enabling the ACTIVE box. The roller connector is modeled with two races, each of which have their own reference frame. Each race is glued to it's connecting member by a shared set of nodes at the race-member interface. The two races are rigid bodies and their six degrees of freedom are related by the effective stiffness of roller elements between them. The six degrees of freedom of each race's reference frame, and the internal reaction forces/moments use the same conventions mentioned previously for the STIFFNESS connectors.

The CONNECTORS menu for the roller bearing is shown in Figure 6.9. The inputs in the roller bearing connectors menu are identical to those of the stiffness bearing, with the exception of the stiffness, damping, unloaded deformation, and bearing load inputs. Selection of ROLLER from the TYPE dropbox in the CONNECTORS menu enables a set of sub-menus specific to the ROLLER connectors. These sub-menus: GEOMETRY, CAGE, CONTACT_GRID, FEMODEL, MATERIAL, and RUNOUT are also shown in Figure 6.9.

The CONTACT_GRID menu contains the fields required to define the contact grid size and tolerances for the roller-race contact analysis. The FEMODEL menu is used to specify the type and number of elements to be used for the mesh of the bearing roller elements and races. The MATERIAL menu contains the material property definition parameters, and the RUNOUT menu can be used to define a bearing runout error. The input parameter definitions for each of these submenus are provided in Tables 6.5 through 6.8.

The GEOMETRY menu contains the user inputs related to the roller geometry. Within this menu, the following roller geometry TYPE options are available: GENERAL, TAPERED, DOUBLETAPERED, SPHERICAL, and BALL. The geometry menu inputs for each roller type are discussed in detail in the following subsections.


MultyX Edit Connector
EXIT
QUIT
GEOMETRY
CAGE
CONTACT_GRID
FEMODEL
MATERIAL
RUNOUT
NAME
IDROTOR1
DIARACE1
AXPOSN1RACE1
AXPOSN2RACE1
DIARACE2
AXPOSN1RACE2
AXPOSN2RACE2
XPOS
YPOS
ZPOS

CONNECTOR 1

ACTIVE ☑

TYPE ROLLERS

MEMBER1TYPE ROTOR

MEMBER2TYPE GROUND

AX 0.0000000000e+000

AY 0.0000000000e+000

AZ 0.0000000000e+000

REFERENCE_RACE OUTER

Figure 6.9 CONNECTOR Menu for Roller Bearing Connector TYPE

Table 6.6 FEMODEL Menu for Roller Bearing Connectors

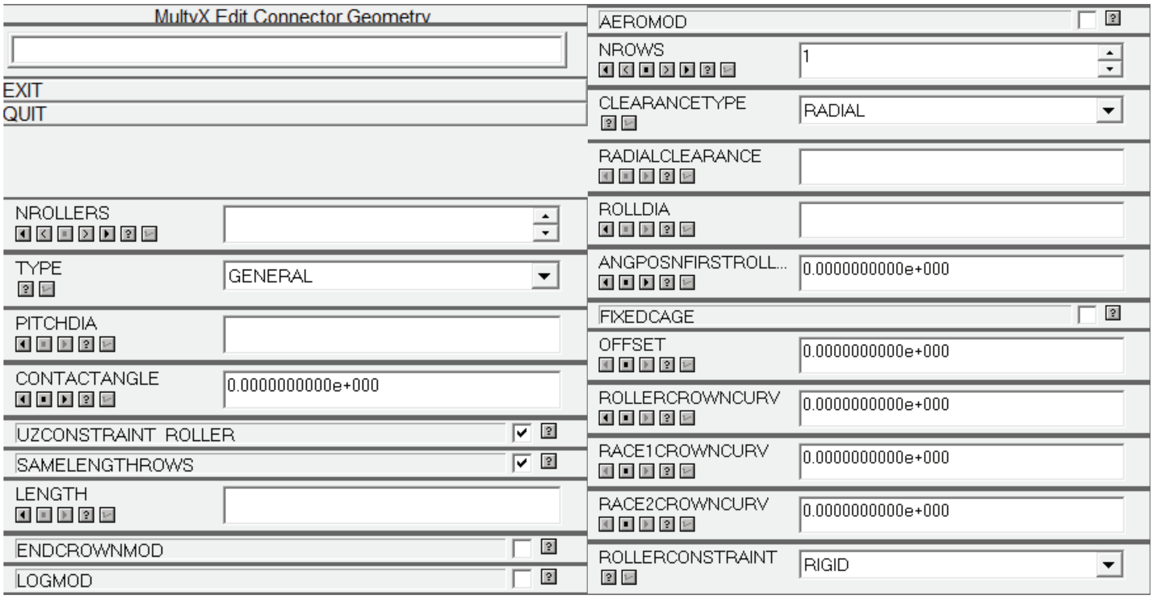
Item	Description
ELEMTYPE	Switch, They type of elements to be used for the splines.
NCIRCDIVS	Integer, The number of circular divisions for the roller bearing races.
NCIRCDIVS2	Integer, The number of circular divisions for the rolling element.
NAXIALDIVS	Integer, The number of axial divisions for the roller bearing races.
NAXIALDIVS2	Integer, The number of axial divisions for the rolling element.

Table 6.7 MATERIAL Menu for Roller Bearing Connectors

Item	Description
SAMEMATERIAL	Switch, If turned on, the same material properties will be defined for the rollers and two races. If turned off, separate material properties can be defined for the rollers and each of the two races. The thermal expansion coefficient and delta temperature inputs are always applied to all three componenets regardless.
POISSON	Float, Poisson's ratio.
DENSITY	Float, Density.
RALEIGHALPHA	Float, The Raleigh damping model assumes that thedamping matrix C for a finite element is is related to the Mass matrix M and stiffness matrix K by the linear relationship: C=alpha*M+beta*K The variable ALPHA is the value of alpha.
RALEIGHBETA	Float, Beta coefficient of the Raleigh damping model.
THERMAL_EXPANSIO...	Float, Thermal expansion coefficient.
DELTA_TEMPERATURE	Float, The temperature increase, relative to the temperature at which the dimensions of the connector are specified.

Table 6.8 RUNOUT Menu for Roller Bearing Connectors

Item	Description
MAGRUNOUT1	Float, Magnitude of the high point of runout error for the race 1.
ANGRUNOUT1	Float, Defines the orientation of the high point of runout error for the race 1. A value of zero degrees will mnove sector no.1 radially outward. This angle is measured using the right hand rule about the connector axis.
MAGRUNOUT2	Float, Magnitude of the high point of runout error for the race 2.
ANGRUNOUT2	Float, Defines the orientation of the high point of runout error for the race 2. A value of zero degrees will mnove sector no.1 radially outward. This angle is measured using the right hand rule about the connector axis.



NROLLERS
TYPE GENERAL
PITCHDIA
CONTACTANGLE 0.0000000000e+000
☑ UZCONSTRAINT ROLLER
☑ SAMELENGTHROWS
LENGTH
☐ ENDCROWNMOD
☐ LOGMOD
☐ AEROMOD
NROWS 1
CLEARANCETYPE RADIAL
RADIALCLEARANCE
ROLLDIA
ANGPOSNFIRSTROLL... 0.0000000000e+000
☐ FIXEDCAGE
OFFSET 0.0000000000e+000
ROLLERCROWNCURV 0.0000000000e+000
RACE1CROWNCURV 0.0000000000e+000
RACE2CROWNCURV 0.0000000000e+000
ROLLERCONSTRAINT RIGID

Figure 6.10 The GENERAL roller GEOMETRY menu.

6.2.1 General Roller Bearings

The number of rollers is the first item in the GEOMETRY menu, shown in Figure 6.10. The nominal contact angle is given by CONTACTANGLE. When CONTACTANGLE is zero, it becomes a cylindrical bearing. When it is nonzero, it can model a tapered roller bearing. The ROLLERCROWNCURVATURE an be controlled to make it model a ball bearing. The CLEARANCE value is the range of radial motion allowed between the two races in the radial direction. The radial space between an individual roller and the outer race or the inner race will be one quarter of this clearance.

The length and the pitch diameters of the rollers are specified in the LENGTH and PITCHDIA respectively. The roller diameter specified in ROLLDIA should be small enough to fit in the space between the races. When the OFFSET is zero, the midsection of the roller coincides with the midsection of the overlapping part of the Z extent of the two races in the bearing. The crowning curvature (inverse of the radius of curvature) of the roller along its length ROLLERCROWNCURV. The crowning curvature of Race1 along its length is given by RACE1CROWNCURV and that for Race2 is given by RACE2CROWNCURV.

ANGPOSNFIRSTROLLER is used to orient the first roller. are accordingly oriented so that they are all evenly spaced. The GEOMETRY menu for the general roller bearing is shown in Figure 6.10. Table 6.9 explains all of the parameters used in the GENERAL roller type GEOMETRY menu. A schematic of the general roller bearing is shown in Figure 6.11.

Table 6.9 Additional items for a GENERAL roller bearing TYPE connector.

Item	Description
NROLLERS	Integer, Number of rollers on the bearing
PITCHDIA	Float, Pitch diameter of the rollers
CONTACTANGLE	Float, Contact angle (Deg) at the rollers
UZCONSTRAINTROLLER	Boolean, Applies a constraint between the roller and inner race in the axial direction. Should be enabled for tapered rollers and disabled for ball/deep groove bearings.
SAMELENGTHROWS	Boolean, When turned on, the rollers in each row will be the same length.
LENGTH	Float, Length of the roller
ENDCROWNMOD	Boolean, Enables the end crown modification for the roller. The end crown modification is symmetric, and has a flat, unmodified length at the middle of the roller length. A crowning radius is applied at the ends of the roller length. Parameters are crown radius and flat length.
LOGMOD	Boolean, turns on the logarithmic modification for the roller. It takes only one parameter-the magnitude of the modification.
AEROMOD	Boolean, Turns on the ’Aero’ modification for the roller. The aero modification is symmetric, and has a flat unmodified length at the middle of the roller length. A crowning radius is applied at the ends of the roller length. The slope is discontinuous at the end of the flat for this modification. Parameters are crown radius, corner radius, and flat length.
NROWS	Integer, Number of rows of rollers.
CLEARANCE	Float, The radial or axial clearance at the rollers, depending upon the type selected.
ROLLDIA	Float, The diameter of the rollers
ANGPOSNFIRSTROLL	Float, The angular position (degrees) of the first roller. Setting this to zero places the center of the first roller at the positive x-axis.
FIXEDCAGE	Boolean, Enabling this feature causes the cage to remain stationary. This can be useful if precise location of the rollers is required.
OFFSET	Float, Axial offset of the roller
ROLLERCROWNCURV	Float, Crown curvature of the rollers
RACE1CROWNCURV	Float, Crown curvature of race 1 of the rollers
RACE2CROWNCURV	Float, Crown curvature of race 2 of the rollers
ROLLERCONSTRAINT	Switch, Controls the type of constraint that is applied to the base of the roller. RIGID: The base of the roller will be undeformed. FLEXIBLE: The base will be allowed to deform using a Fourier series in the circular direction and a plynomial series in the axial direction. Oly those terms in the series corresponding to rigid body motion will be constrained.

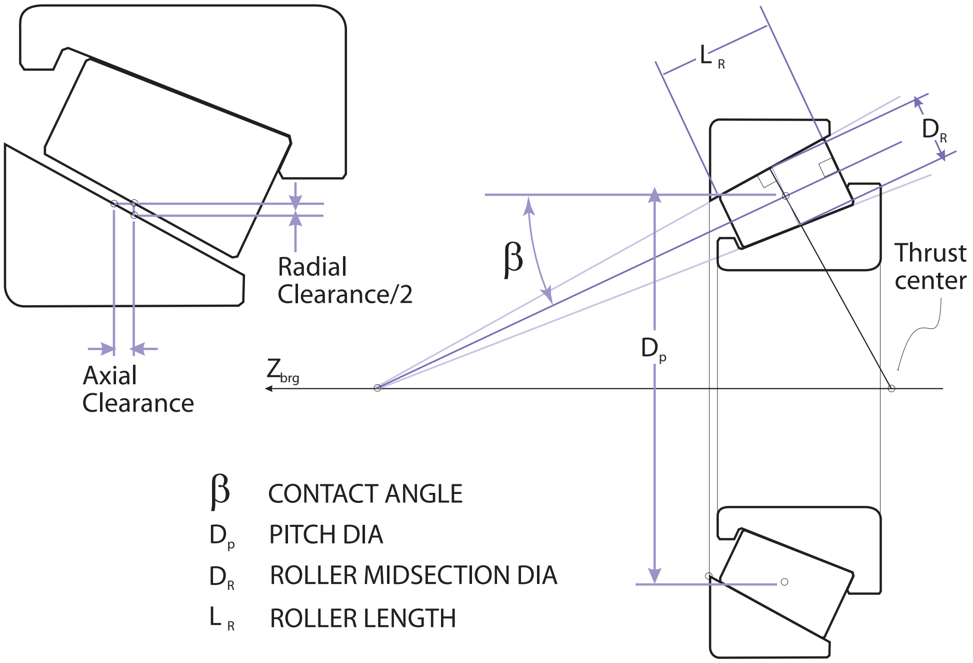
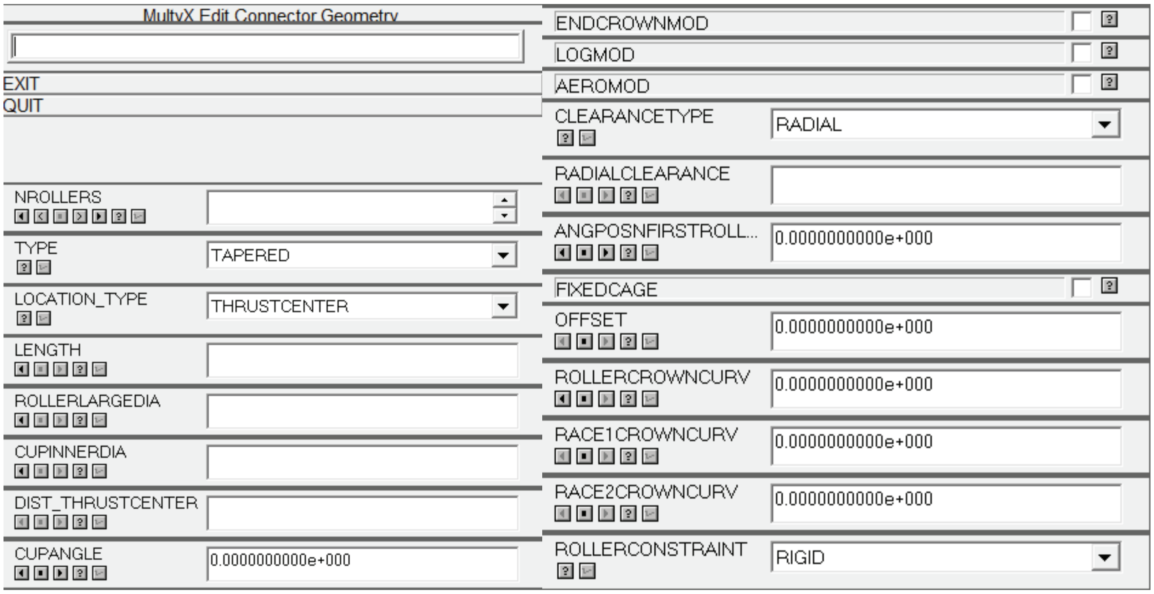

L R
D R
Thrust
center
β
D p
Radial
Clearance/2
Axial
Clearance
Z brg
β CONTACT ANGLE
D p PITCH DIA
D R ROLLER MIDSECTION DIA
L R ROLLER LENGTH

Figure 6.11 The GENERAL roller bearing schematic.



MultyX Edit Connector Geometry

EXIT

QUIT

NROLLERS

TYPE: TAPERED

LOCATION_TYPE: THRUSTCENTER

LENGTH

ROLLERLARGEDIA

CUPINNERDIA

DIST_THRUSTCENTER

CUPANGLE: 0.0000000000e+000

ENDCROWNMOD ☐

LOGMOD ☐

AEROMOD ☐

CLEARANCETYPE: RADIAL

RADIALCLEARANCE

ANGPOSNFIRSTROLL...: 0.0000000000e+000

FIXEDCAGE ☐

OFFSET: 0.0000000000e+000

ROLLERCROWNCURV: 0.0000000000e+000

RACE1CROWNCURV: 0.0000000000e+000

RACE2CROWNCURV: 0.0000000000e+000

ROLLERCONSTRAINT: RIGID

Figure 6.12 The TAPERED roller GEOMETRY menu.

6.2.2 Tapered Roller Bearings

The TAPERED roller bearing GEOMETRY menu shown in Figure 6.12 is very similar to the geometry menu for the general roller bearing. The tapered roller bearing geometry menu input parameters represent the parameters typically listed on an engineering drawing or data sheet of a tepered roller bearing. Figure 6.13 shows the tapered roller geomtry and schematic. The LOCATION_TYPE input allows the user to specify the bearing origin at either the THRUSTCENTER or at the ROLLERCENTER. DIST_THRUSTCENTER specifies the distance between the thrust center point and the point on the cup where the inner diameter is smallest. The CUPINNERDIA is the inside diameter of the cup at this point. CUPANGLE sets the half-cone angle of the cup. A positive cone angle places the bearing on the positive Z side of the roller origin, where Z is the shaft axis. The remaining inputs fields are identical to those described within the general roller bearing section. Table 6.10 provides a detailed description of each of the tapered roller bearing geometry menu inputs.

Table 6.10 Additional items for a TAPERED roller bearing TYPE connector.

Item	Description
NROLLERS	Integer, Number of rollers on the bearing
LOCATION_TYPE	Switch, The method to be used to locate the bearing. If ROLLERCENTER is selected, the location of the center of the roller is considered to be the location of the bearing. If THRUSTCENTER is selected, the location of the bearing is its center of thrust.
LENGTH	Float, Length of the roller
ROLLERLARGEDIA	Float, The diameter at the large end of the roller.
CUPINNERDIA	Float, The diameter at the smaller end of the cup.
DIST_THRUSTCENTER	Float, The axial distance of the thrust center from the axial section containing the smaller diameter of the cup. This is always positive because the thrust center can only lie on a specific side of the cup's smaller diameter.
CUPANGLE	Float, The half cone angle of the cup. A positive value implies that the apex of the cone lies on the +ve Z side of the roller. The Z axis is the shaft axis. This value is in Degrees.
ENDCROWNMOD	Boolean, Enables the end crown modification for the roller. The end crown modification is symmetric, and has a flat, unmodified length at the middle of the roller length. A crowning radius is applied at the ends of the roller length. Parameters are crown radius and flat length.
LOGMOD	Boolean, turns on the logarithmic modification for the roller. It takes only one parameter-the magnitude of the modification.
AEROMOD	Boolean, Turns on the 'Aero' modification for the roller. The aero modification is symmetric, and has a flat unmodified length at the middle of the roller length. A crowning radius is applied at the ends of the roller length. The slope is discontinuous at the end of the flat for this modification. Parameters are crown radius, corner radius, and flat length.
NROWS	Integer, Number of rows of rollers.
CLEARANCE	Float, The radial or axial clearance at the rollers, depending upon the type selected.
ANGPOSNFIRSTROLL	Float, The angular position (degrees) of the first roller. Setting this to zero places the center of the first roller at the positive x-axis.
FIXEDCAGE	Boolean, Enabling this feature causes the cage to remain stationary. This can be useful if precise location of the rollers is required.
OFFSET	Float, Axial offset of the roller
ROLLERCROWNCURV	Float, Crown curvature of the rollers
RACE1CROWNCURV	Float, Crown curvature of race 1 of the rollers
RACE2CROWNCURV	Float, Crown curvature of race 2 of the rollers
ROLLERCONSTRAINT	Switch, Controls the type of constraint that is applied to the base of the roller. RIGID: The base of the roller will be undeformed. FLEXIBLE: The base will be allowed to deform using a Fourier series in the circular direction and a plynomial series in the axial direction. Oly those terms in the series corresponding to rigid body motion will be constrained.

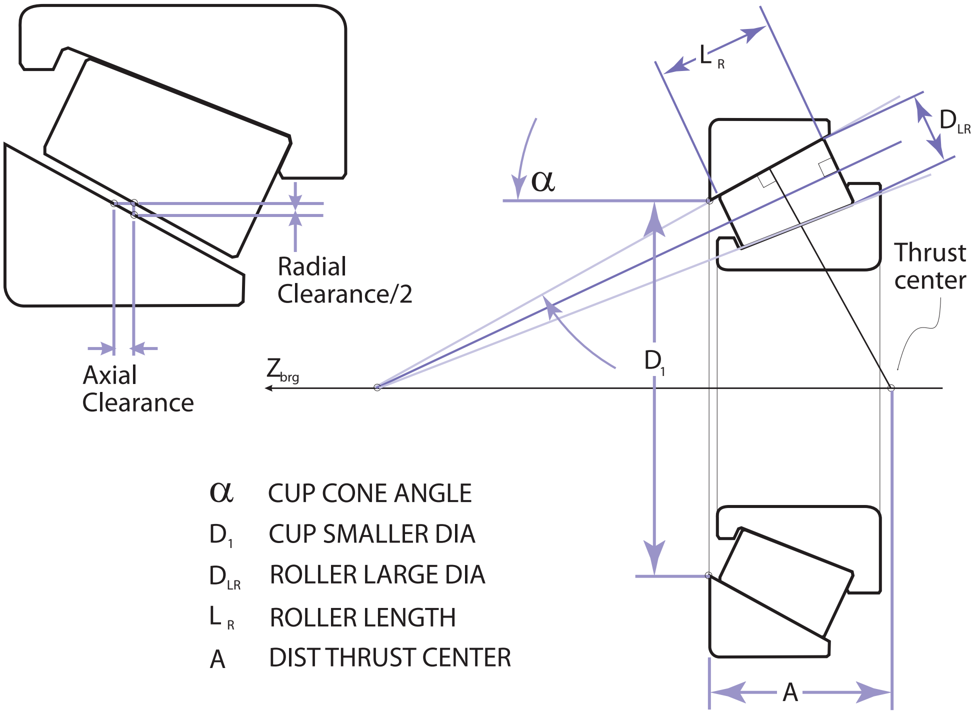

Radial
Clearance/2
Axial
Clearance
Z_{brg}
α
L_R
D_{LR}
D_1
Thrust
center
A
α CUP CONE ANGLE
D_1 CUP SMALLER DIA
D_{LR} ROLLER LARGE DIA
L_R ROLLER LENGTH
A DIST THRUST CENTER

Figure 6.13 The TAPERED roller bearing schematic.

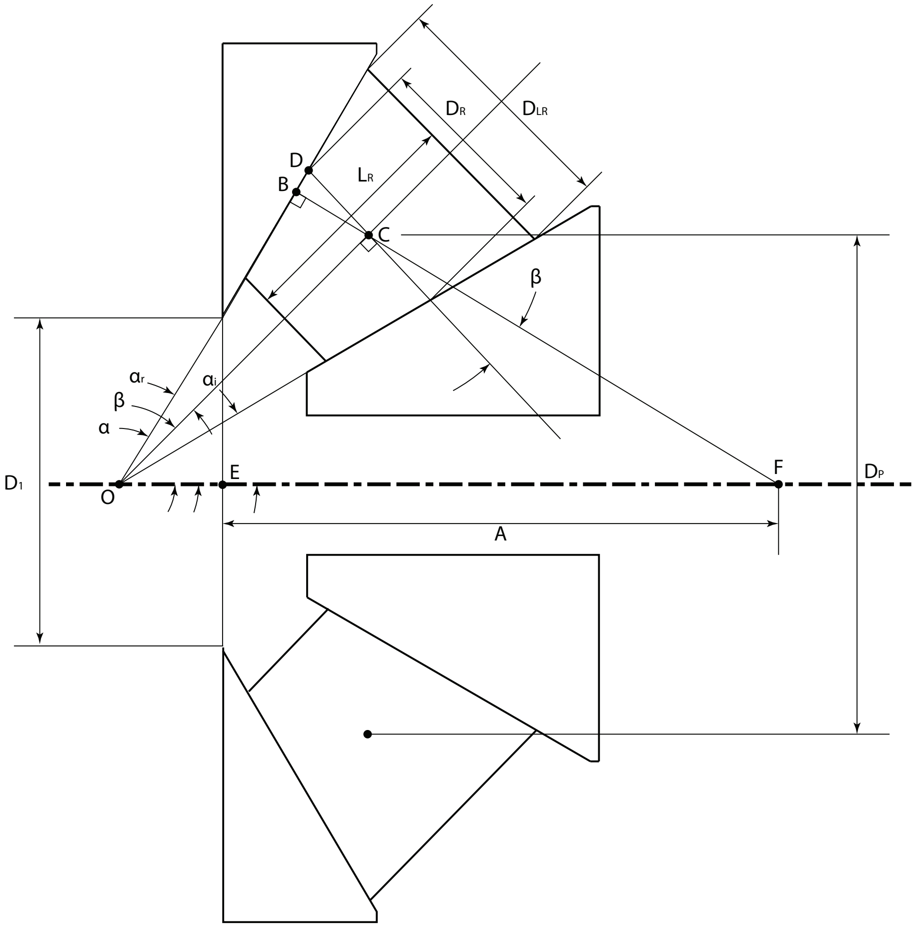


Figure 6.14 The TAPERED roller bearing calculations.

6.2.2.1 Tapered Roller Bearing Calcualtions The variables and parameters shown in the schematic of Figure 6.14 are used by *Calyx* to generate the 3D mesh of the tapered roller bearing geometry. The input parameters and calculated variables are shown on the following page, along with the procedure used to calculate the unknown variables.

Inputs:

L_R = Roller Length

D_1 = Cup Inner Dia

D_{LR} = Roller Large End Dia

A = Distance, Thrust Center to Cup Inner Dia

α = Cup Half-Cone Angle

Calculated:

α_r = Roller Half-Cone Angle

β = Contact Angle

α_i = Inner Cone Angle

D_P = Pitch Diameter

D_R = Roller Mid-Section Diameter

Calculations:

$$OE = D_1 / (2\tan\alpha)$$

$$OF = OE + A = D_1 / (2\tan\alpha) + A$$

$$OB = OF * \cos\alpha = [D_1 / (2\tan\alpha) + A] * \cos\alpha$$

$$BC = OB * \tan\alpha_r$$

$$CD = BC / \cos\alpha_r = (OB * \tan\alpha_r) / \cos\alpha_r = OB * \sin\alpha_r / \cos^2\alpha_r$$

$$D_{LR} = 2 * [CD + (L_R / 2) * \tan\alpha_r]$$

$$\boxed{D_{LR} = 2 * [(OB * \sin\alpha_r / \cos^2\alpha_r) + (L_R / 2) * \tan\alpha_r]} \longrightarrow \text{Eq (1)}$$

Everything in Eq (1) is known, except α_r. Solve Eq (1) for α_r.

Now Calculate:

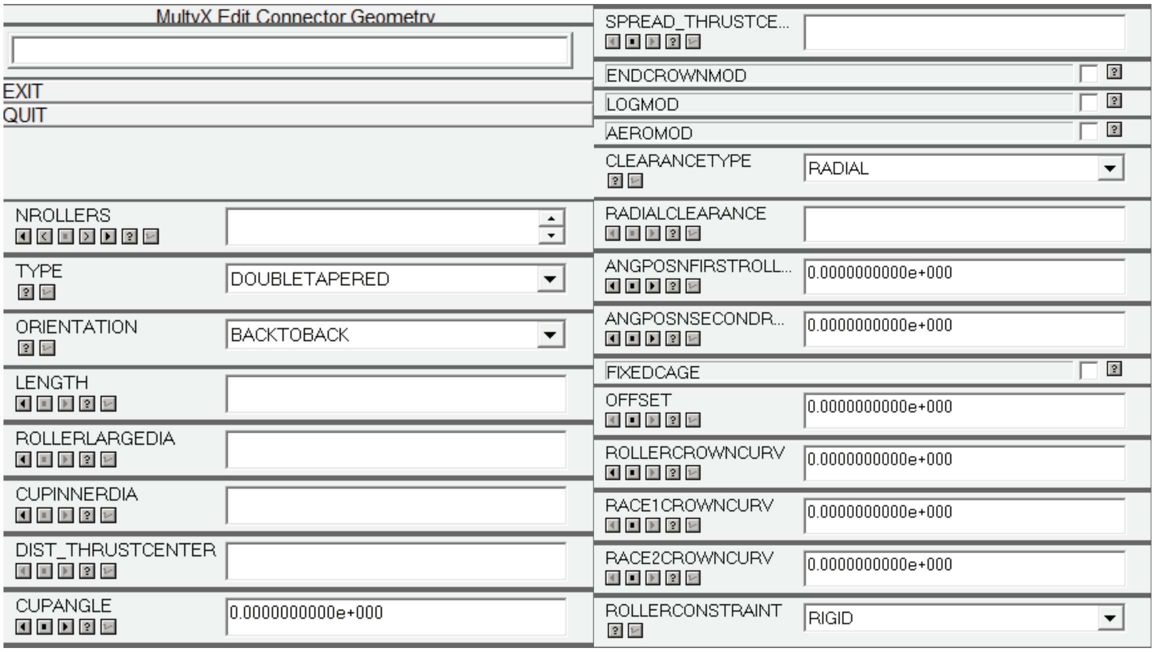
$$OC = OB / \cos\alpha_r$$

$$\beta = \alpha - \alpha_r$$

$$\alpha_i = \alpha - 2\alpha_r$$

$$D_P = 2 * OC \sin\beta$$

$$D_R = 2 * OC \tan\beta$$



TYPE: DOUBLETAPERED
ORIENTATION: BACKTOBACK
CUPANGLE: 0.0000000000e+000
ENDCROWNMOD ☐
LOGMOD ☐
AEROMOD ☐
CLEARANCETYPE: RADIAL
ANGPOSNFIRSTROLL...: 0.0000000000e+000
ANGPOSNSECONDR...: 0.0000000000e+000
FIXEDCAGE ☐
OFFSET: 0.0000000000e+000
ROLLERCROWNCURV: 0.0000000000e+000
RACE1CROWNCURV: 0.0000000000e+000
RACE2CROWNCURV: 0.0000000000e+000
ROLLERCONSTRAINT: RIGID

Figure 6.16 The DOUBLETAPERED roller GEOMETRY menu.

6.2.3 Double Tapered Roller Bearings

The DOUBLETAPERED roller bearing GEOMETRY menu is shown in Figure 6.16. The double tapered roller geometry menu inputs are nearly identical to the single tapered roller inputs, with the exception of the ORIENTATION and SPREAD_THRUSTCENTERS input fields. The ORIENTATION switch selects the the orientation of the roller rows. In the FACETOFACE orientation, the roller reaction force vectors make an ’X’ if looking at the bearing cross-section view. In the BACKTOBACK orientation, roller reaction force vectors form an ’O’. Figures 6.17 and 6.18 show the shematics for the face to face and back to back orientations, respectively. The SPREAD_THRUSTCENTERS input is the axial distance between the two thrust centers of the two rows of rollers. The double tapered roller bearing origin is always at the geometric center of the two rows of rollers since there are two thrust centers. The remaining inputs are identical to those described in Table 6.10 for the tapered roller bearing.

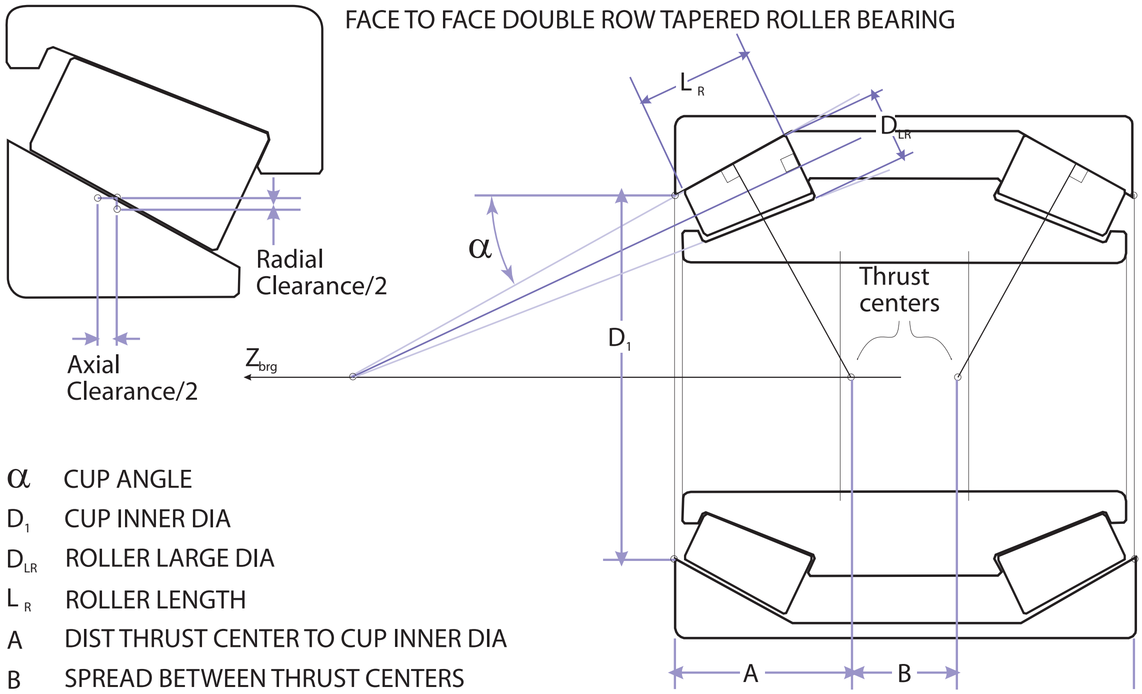

FACE TO FACE DOUBLE ROW TAPERED ROLLER BEARING
L R
DLR
α
Radial Clearance/2
Axial Clearance/2
Zbrg
D1
Thrust centers
A
B
α CUP ANGLE
D1 CUP INNER DIA
DLR ROLLER LARGE DIA
L R ROLLER LENGTH
A DIST THRUST CENTER TO CUP INNER DIA
B SPREAD BETWEEN THRUST CENTERS

Figure 6.17 The DOUBLETAPERED roller bearing schematic (face to face).

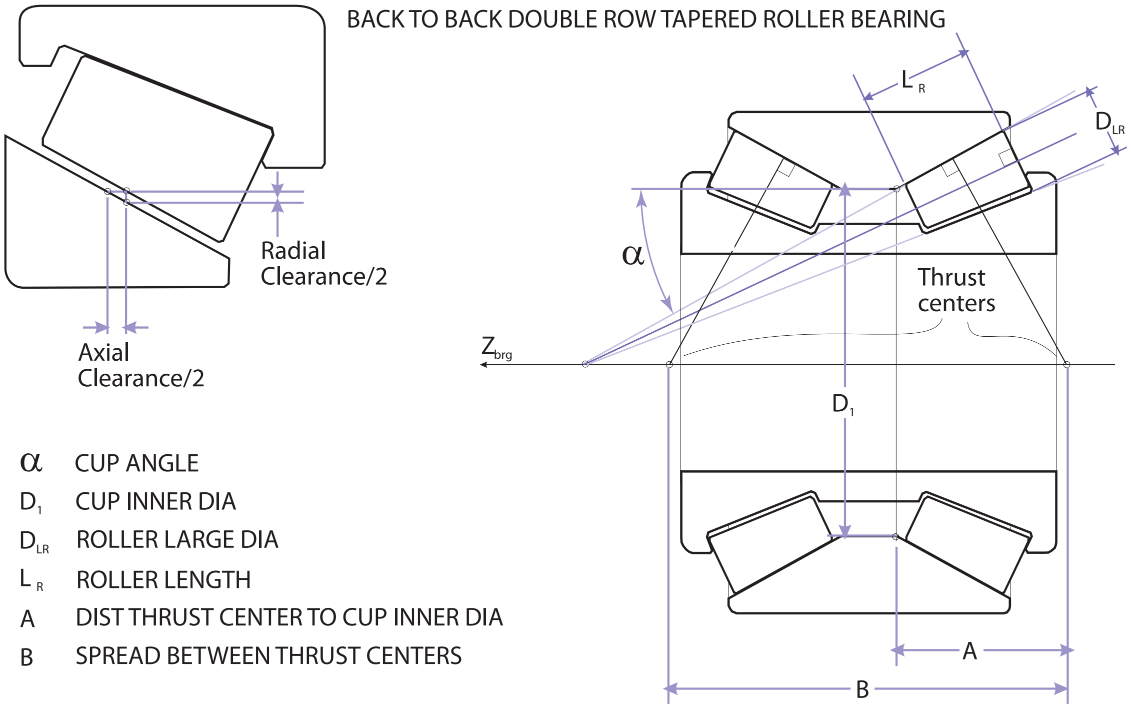
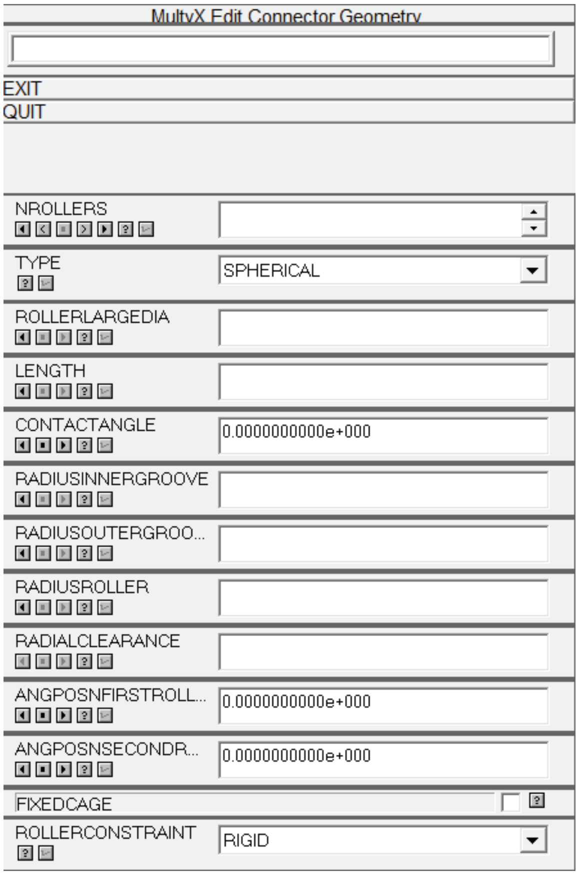

BACK TO BACK DOUBLE ROW TAPERED ROLLER BEARING
Radial Clearance/2
Axial Clearance/2
L R
D LR
α
Thrust centers
Z brg
D 1
A
B
α CUP ANGLE
D 1 CUP INNER DIA
D LR ROLLER LARGE DIA
L R ROLLER LENGTH
A DIST THRUST CENTER TO CUP INNER DIA
B SPREAD BETWEEN THRUST CENTERS

Figure 6.18 The DOUBLETAPERED roller bearing schematic (back to back).



NROLLERS
TYPE: SPHERICAL
ROLLERLARGEDIA
LENGTH
CONTACTANGLE: 0.0000000000e+000
RADIUSINNERGROOVE
RADIUSOUTERGROO...
RADIUSROLLER
RADIALCLEARANCE
ANGPOSNFIRSTROLL...: 0.0000000000e+000
ANGPOSNSECONDR...: 0.0000000000e+000
FIXEDCAGE ☐
ROLLERCONSTRAINT: RIGID

Figure 6.19 The SPHERICAL bearing GEOMETRY menu.

6.2.4 Spherical Roller Bearings

The fourth TYPE of roller bearing option available within the GEOMETRY menu is the SPHERICAL roller bearing. The GEOMETRY menu with the spherical roller bearing type selected is shown in Figure 6.19. ROLLERLARGEDIA specifies the diameter at the midpoint of the roller as shown in the schematic in Figure 6.20. The RADIUSINNERGROOVE and RADIUSOUTERGROOVE set the radii of the shperical grooves between which the rollers sit. The outer groove is modeled with one, continuous groove, while the inner groove is separate for each individual roller. The difference between the outer and inner groove radii must at least be equal to the ROLLERLARGEDIA plus the RADIALCLEARANCE. The roller radius is specified in the RADIUSROLLER input field. The curvature of the roller is the inverse of this value. ANGPOSNFIRSTROW and ANGPOSNSECONDROW set the starting angular position of the first rollers of each of the two rows. A value of zero set the middle of the first roller coincident with the X axis. All of the spherical bearing GEOMETRY menu inputs are summarized in Table 6.11.

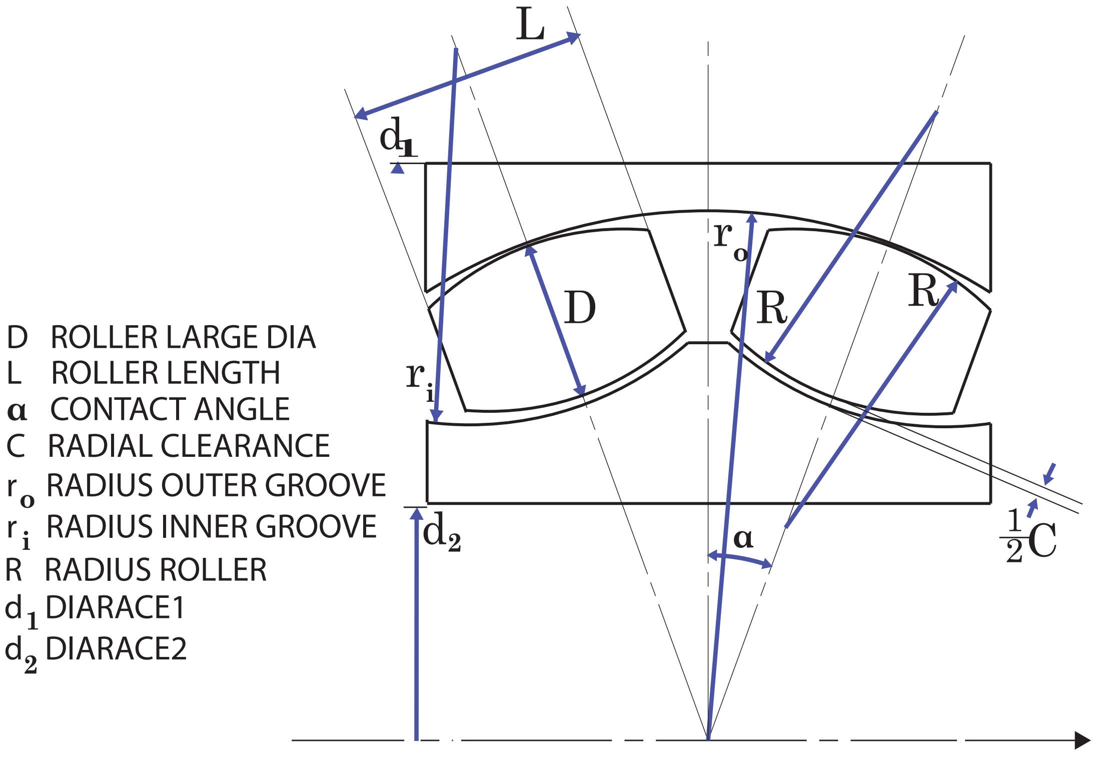
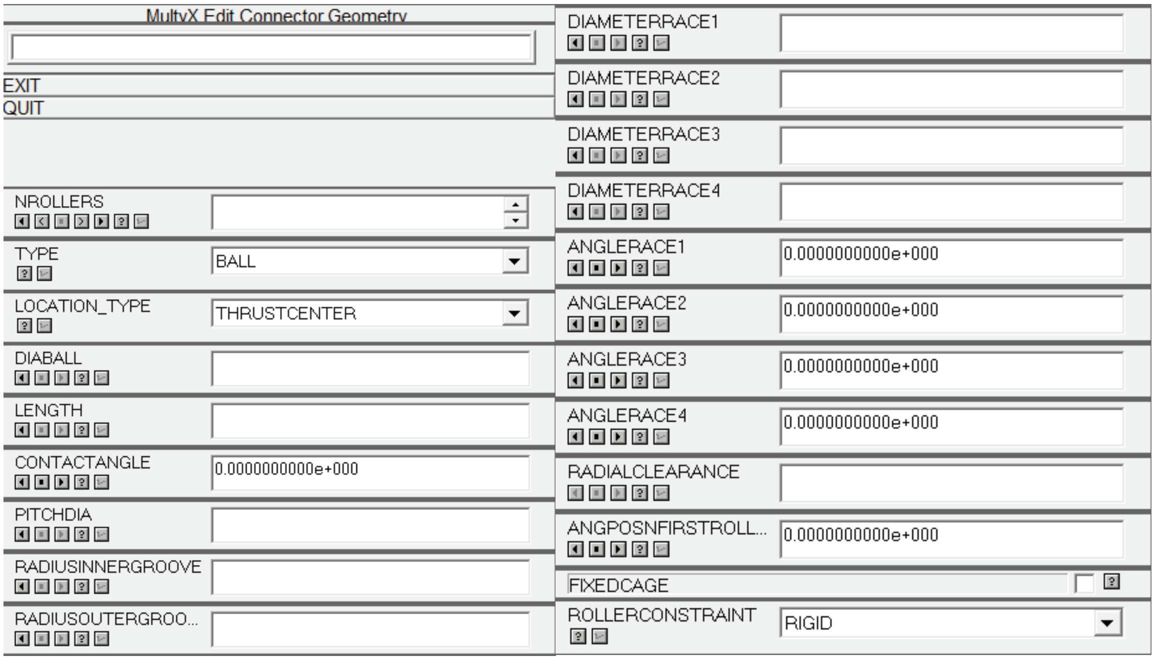

L
d_1
r_o
D
R
R
r_i
d_2
α
$\frac{1}{2}C$
D ROLLER LARGE DIA
L ROLLER LENGTH
α CONTACT ANGLE
C RADIAL CLEARANCE
r_o RADIUS OUTER GROOVE
r_i RADIUS INNER GROOVE
R RADIUS ROLLER
d_1 DIARACE1
d_2 DIARACE2

Figure 6.20 The SPHERICAL bearing bearing schematic (face to face).

Table 6.11 Additional items for a SPHERICAL roller bearing TYPE connector.

Item	Description
NROLLERS	Integer, Number of rollers on the bearing
ROLLERLARGEDIA	Float, The diameter at the large end of the roller.
LENGTH	Float, Length of the roller
CONTACTANGLE	Float, The angle of nominal contact of the rollers (degrees).
CUPINNERDIA	Float, The diameter at the smaller end of the cup.
RADIUSINNERGROOVE	Float, The radius of the roller groove at the inner bearing race.
RADIUSOUTERGROOVE	Float, The radius of the roller groove at the outer bearing race.
RADIUSROLLER	Float, The radius of the roller.
RADIALCLEARANCE	Float, The radial clearance between the roller and inner and outer grooves. The clearance value is the total space between the roller and inner groove, plus the space between the roller and outer groove. The radial position of the roller is calculated such that the space on both sides of the roller is equal.
ANGPOSNFIRSROLLER	Float, The angular position (degrees) of the first roller of row 1.
ANGPOSNSECONDROLLER	Float, The angular position (degrees) of the first roller of row 2.
FIXEDCAGE	Boolean, Enabling this feature causes the cage to remain stationary. This can be useful if precise location of the rollers is required.
ROLLERCONSTRAINT	Switch, Controls the type of constraint that is applied to the base of the roller. RIGID: The base of the roller will be undeformed. FLEXIBLE: The base will be allowed to deform using a Fourier series in the circular direction and a plynomial series in the axial direction. Oly those terms in the series corresponding to rigid body motion will be constrained.


MultyX Edit Connector Geometry
EXIT
QUIT
NROLLERS
DIABALL
LENGTH
PITCHDIA
RADIUSINNERGROOVE
RADIUSOUTERGROO...
DIAMETERRACE1
DIAMETERRACE2
DIAMETERRACE3
DIAMETERRACE4
RADIALCLEARANCE
FIXEDCAGE ☐

TYPE: BALL
LOCATION_TYPE: THRUSTCENTER
CONTACTANGLE: 0.0000000000e+000
ANGLERACE1: 0.0000000000e+000
ANGLERACE2: 0.0000000000e+000
ANGLERACE3: 0.0000000000e+000
ANGLERACE4: 0.0000000000e+000
ANGPOSNFIRSTROLL...: 0.0000000000e+000
ROLLERCONSTRAINT: RIGID

Figure 6.21 The BALL bearing GEOMETRY menu.

6.2.5 Ball Bearings

The BALL bearing TYPE is the final roller bearing option. The ball bearing GEOMETRY menu is shown in Figure 6.21. The ball bearing origin defined within the CONNECTORS menu can be placed at either the ROLLERCENTER or the THRUSTCENTER using the LOCATION_TYPE switch within the geometry menu. The DIABALL and LENGTH input parameters set the ball diameter and length, respectively. The FE model cannot be a complete shpere, so it is modeled as a cylinder with a curvature. The curvature is calculated as the inverse of the ball radius. The LENGTH parameter then specifies the actual length of curved cylinder. The RADIUSINNERGROOVE and RADIUSOUTERGROOVE parameters set the radii of the grooves of the inner and outer bearing races. The curvature of these grooves is the inverse of the radii. The DIAMETERRACE inputs specify the diameters at the four points shown in the ball bearing schematics shown in Figures 6.22 and 6.23. The ANGLERACE parameters specify the angle the raceway makes with the horizontal at the four same four points where the diameters are specified. The remaining inputs are similar to those described for previous roller bearing types. Table 10.1 provides a description of all of the ball bearing geometry menu inputs. .

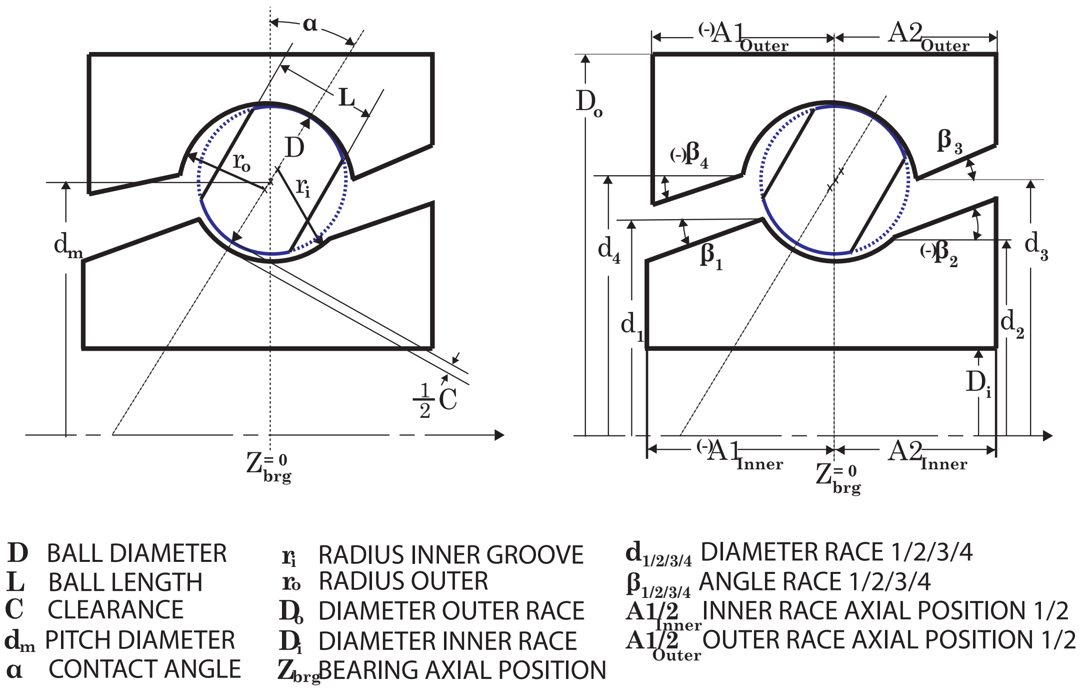

α
L
D
r_o
r_i
d_m
$\frac{1}{2}C$
$Z_{brg}^{=0}$
$^{(-)}A1_{Outer}$
$A2_{Outer}$
D_o
$^{(-)}\beta_4$
β_3
β_1
$^{(-)}\beta_2$
d_4
d_3
d_1
d_2
D_i
$^{(-)}A1_{Inner}$
$A2_{Inner}$
$Z_{brg}^{=0}$
D BALL DIAMETER
L BALL LENGTH
C CLEARANCE
d_m PITCH DIAMETER
α CONTACT ANGLE
r_i RADIUS INNER GROOVE
r_o RADIUS OUTER
D_o DIAMETER OUTER RACE
D_i DIAMETER INNER RACE
Z_{brg} BEARING AXIAL POSITION
$d_{1/2/3/4}$ DIAMETER RACE 1/2/3/4
$\beta_{1/2/3/4}$ ANGLE RACE 1/2/3/4
$A1/2_{Inner}$ INNER RACE AXIAL POSITION 1/2
$A1/2_{Outer}$ OUTER RACE AXIAL POSITION 1/2

Figure 6.22 The BALL bearing bearing schematic (roller center).

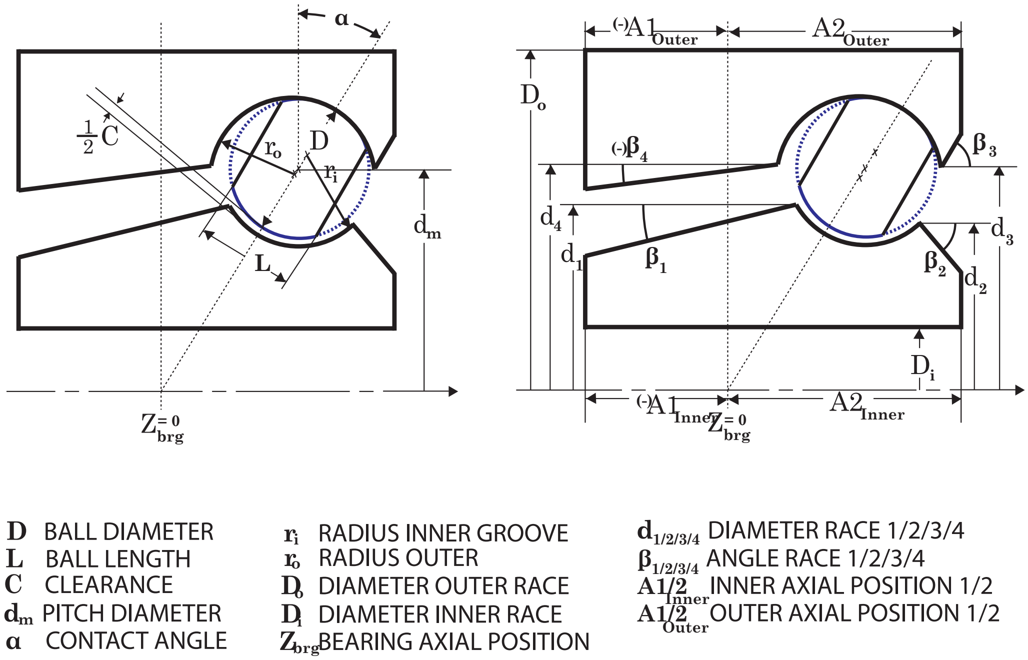

α
$\frac{1}{2}$C
r_o
D
r_i
d_m
L
$Z_{brg}^{=0}$
$^{(-)}A1_{Outer}$
$A2_{Outer}$
D_o
$^{(-)}β_4$
$β_3$
d_4
d_1
$β_1$
$β_2$
d_3
d_2
D_i
$^{(-)}A1_{Inner}$
$Z_{brg}^{=0}$
$A2_{Inner}$
D BALL DIAMETER
L BALL LENGTH
C CLEARANCE
d_m PITCH DIAMETER
α CONTACT ANGLE
r_i RADIUS INNER GROOVE
r_o RADIUS OUTER
D_o DIAMETER OUTER RACE
D_i DIAMETER INNER RACE
Z_{brg} BEARING AXIAL POSITION
$d_{1/2/3/4}$ DIAMETER RACE 1/2/3/4
$β_{1/2/3/4}$ ANGLE RACE 1/2/3/4
$A1/2_{Inner}$ INNER AXIAL POSITION 1/2
$A1/2_{Outer}$ OUTER AXIAL POSITION 1/2

Figure 6.23 The BALL bearing bearing schematic (thrust center).

Table 6.12 Additional items for a BALL bearing TYPE connector.

Item	Description
NROLLERS	Integer, Number of rollers on the bearing
DIABALL	Float, The diameter of the balls in the bearing.
LENGTH	Float, The length of the ball perpendicular to the contact angle. Needed because an actual sphere cannot be modeled.
CONTACTANGLE	Float, The angle of nominal contact of the rollers (degrees).
PITCHDIA	Float, The pitch circle diameter of the ball bearings.
RADISUINNERGROOVE	Float, The radius of the roller groove at the inner bearing race.
RADIUSOUTERGROOVE	Float, The radius of the roller groove at the outer bearing race.
DIAMETERRACE1	Float, The diameter of the inner raceway at location one.
DIAMETERRACE2	Float, The diameter of the inner raceway at location two.
DIAMETERRACE3	Float, The diameter of the outer raceway at location three.
DIAMETERRACE4	Float, The diameter of the outer raceway at location four.
ANGLERACE1	Float, The angle the raceway makes with the horizontal at location one. Positive is away from the pitch diameter.
ANGLERACE2	Float, The angle the raceway makes with the horizontal at location two. Positive is away from the pitch diameter.
ANGLERACE3	Float, The angle the raceway makes with the horizontal at location three. Positive is away from the pitch diameter.
ANGLERACE4	Float, The angle the raceway makes with the horizontal at location four. Positive is away from the pitch diameter.
RADIALCLEARANCE	Float, The radial clearance between the roller and inner and outer grooves. The clearance value is the total space between the roller and inner groove, plus the space between the roller and outer groove. The radial position of the roller is calculated such that the space on both sides of the roller is equal.
ANGPOSNFIRSROLLER	Float, The angular position (degrees) of the first roller of row 1.
FIXEDCAGE	Boolean, Enabling this feature causes the cage to remain stationary. This can be useful if precise location of the rollers is required.
ROLLERCONSTRAINT	Switch, Controls the type of constraint that is applied to the base of the roller. RIGID: The base of the roller will be undeformed. FLEXIBLE: The base will be allowed to deform using a Fourier series in the circular direction and a plynomial series in the axial direction. Oly those terms in the series corresponding to rigid body motion will be constrained.

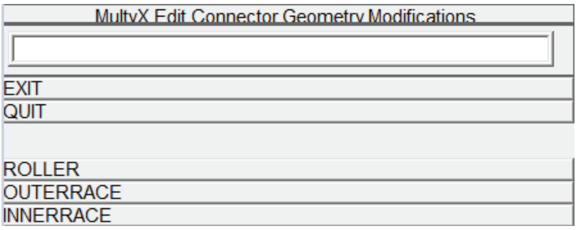
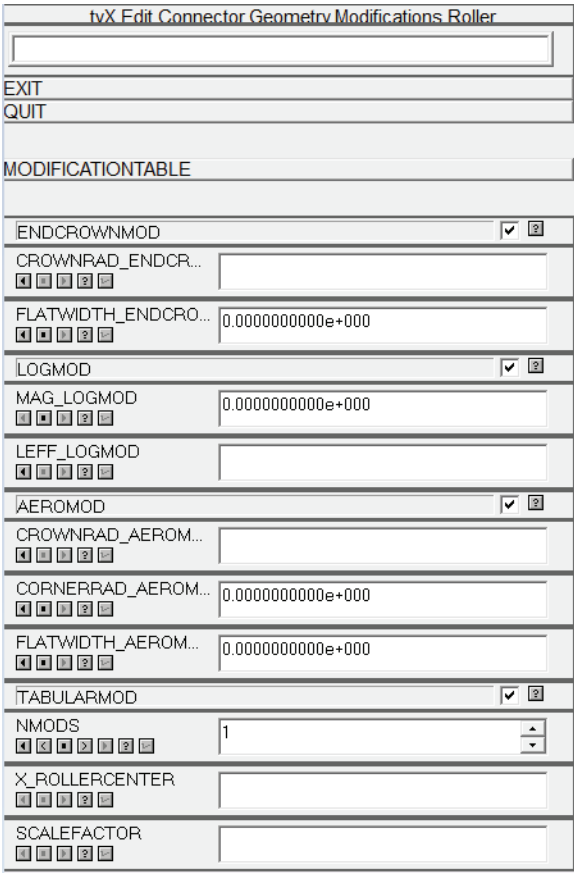

MultyX Edit Connector Geometry Modifications
EXIT
QUIT
ROLLER
OUTERRACE
INNERRACE

Figure 6.24 The roller bearing MODIFICATIONS menu.


tyX Edit Connector Geometry Modifications Roller
EXIT
QUIT
MODIFICATIONTABLE

ENDCROWNMOD ☑
CROWNRAD_ENDCR...
FLATWIDTH_ENDCRO... 0.0000000000e+000
LOGMOD ☑
MAG_LOGMOD 0.0000000000e+000
LEFF_LOGMOD
AEROMOD ☑
CROWNRAD_AEROM...
CORNERRAD_AEROM... 0.0000000000e+000
FLATWIDTH_AEROM... 0.0000000000e+000
TABULARMOD ☑
NMODS 1
X_ROLLERCENTER
SCALEFACTOR

Figure 6.25 The ROLLER modifications menu.

6.2.6 Roller Bearing Modifications

Roller bearing modifications can be added within the MODIFICATIONS submenu of the GEOMETRY menu. The roller, inner race, and outer race can be modified by selecting one of the three submenus shown in Figure 6.24. The ROLLER modifications menu is shown in Figure 6.25. The OUTERRACE and INNERRACE menus contain only the modification table option.

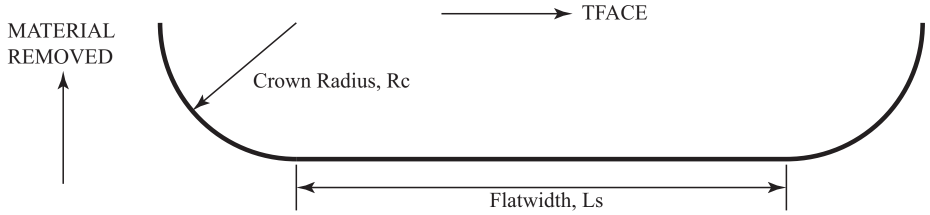


Figure 6.26 The roller end crown modification.

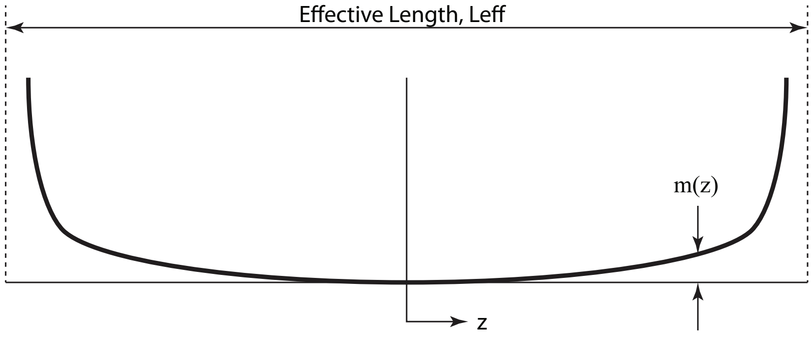


Figure 6.27 The roller logarithmic modification.

6.2.6.1 End Crown Modification The end crown modification is enabled by selecting the ENDCROWNMOD box within the ROLLER modification menu. The end crown modification requires the two inputs shown in the schematic in Figure 6.26, CROWNRAD_ENDCROWN & FLATWIDTH_ENDCROWN.

6.2.6.2 Logarithmic Modification The logarithmic modification is enabled by selecting the LOGMOD box within the ROLLER modification menu. The schematic for the log mod is shown in Figure 6.27. The governing equation for the logarithmic modification is $m(z) = A * ln[(1 - (2z/L_{eff})^2)]$, where A is MAG_LOGMOD and L_{eff} is the effective length, LEFF_LOGMOD.

6.2.6.3 Aero Modification The aero modification is enabled by selecting the AEROMOD checkbox within the ROLLER modification menu. The three input parameters, CROWNRAD_AEROMOD, CORNERRAD_AEROMOD, and FLATWIDTH_AEROMOD are shown in the schematic of the aero modification in Figure 6.28.

6.2.6.4 Modification Table A custom modification can be applied by selecting the TABULARMOD checkbox within the ROLLER, OUTERRACE, or INNERRACE modification menus. Selection of the TABULARMOD box brings up the NMODS, X_ROLLERCENTER, and SCALEFACTOR inputs, as well as the MODIFICATIONTABLE menu. NMODS sets the number of data points to use. X_ROLLERCENTER sets the center point of the modification data in the roller length direction. The defualt X value of 0 places the center point of the modification at the roller center. If defined by a non-zero value, the SCALEFACTOR input is used to scale the modification magnitude data by multiplying each magnitude by the factor. A SCALEFACTOR of 1 or 0 results in unscaled magnitude values.

Figure 6.29 contains the modification table inputs: IMOD, X, and MAGNITUDE. IMOD is the instance of the modifcation curve data point, X is the distance from the center point of the modification in the roller length direction, and MAGNITUDE is the modification magnitude (material removed).

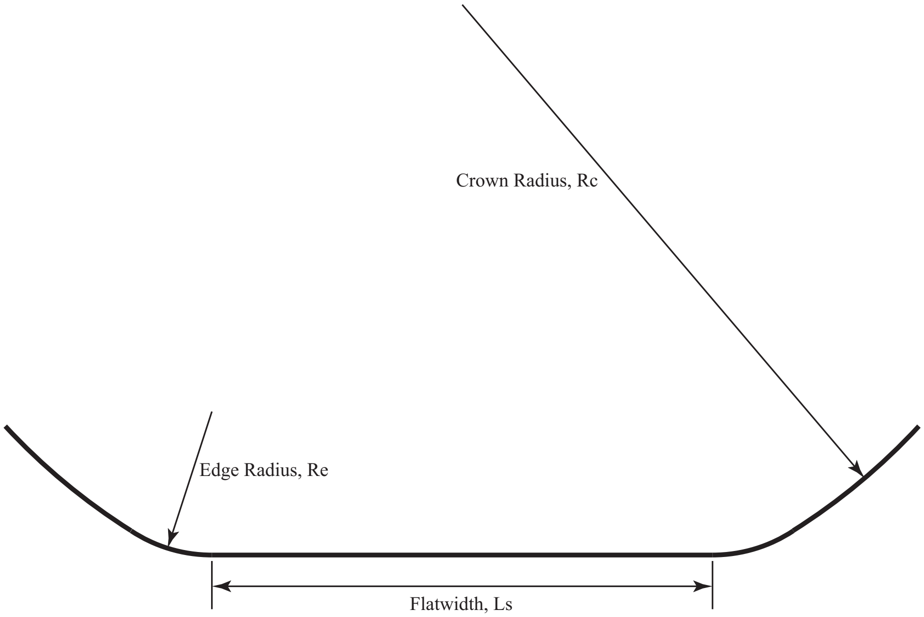
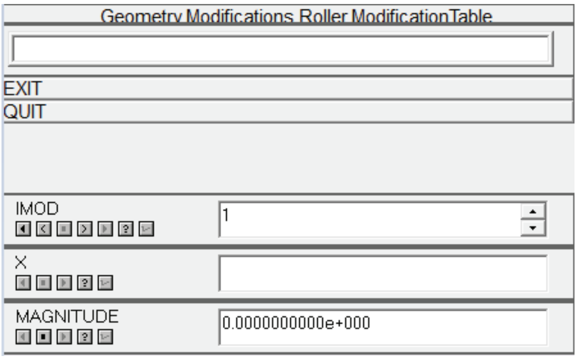

Crown Radius, Rc
Edge Radius, Re
Flatwidth, Ls

Figure 6.28 The roller aero modification.


Geometry Modifications Roller ModificationTable
EXIT
QUIT

IMOD 1

X

MAGNITUDE 0.0000000000e+000

Figure 6.29 The roller MODIFICATIONTABLE menu

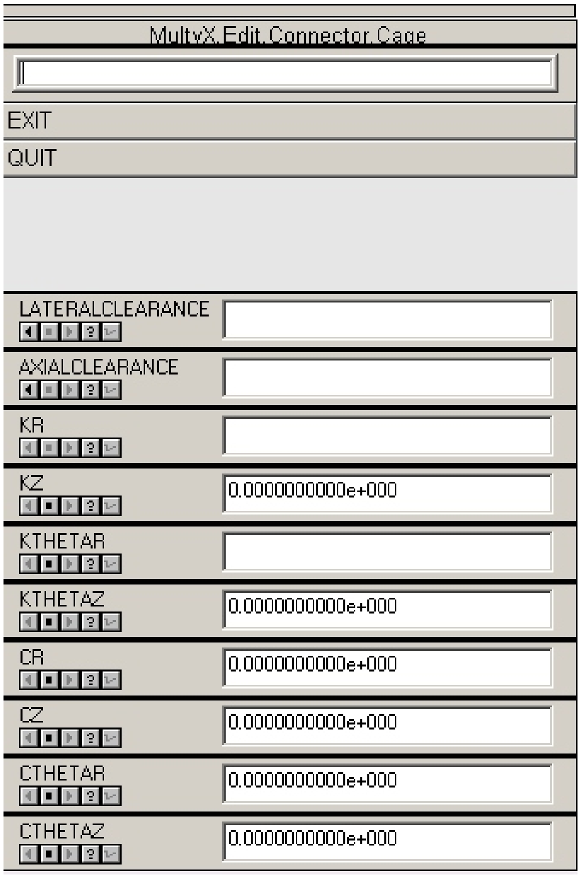
Table 6.13 Roller bearing cage menu

Item	Description
LATERALCLEARANCE	Float, Lateral clearance between the roller and the cage
AXIALCLEARANCE	Float, Axial clearance between the roller and the cage
KR	Float, Radial stiffness K_r between the bearing cage and Race2
KZ	Float, Axial stiffness K_z between the bearing cage and Race2
KTHETAR	Float, Bending stiffness K_{θ_r} between the bearing cage and Race2
KTHETAZ	Float, Torsional stiffness K_{θ_z} between the bearing cage and Race2
CR	Float, Radial damping C_r between the bearing cage and Race2
CZ	Float, Axial damping C_z between the bearing cage and Race2
CTHETAR	Float, Bending damping C_{θ_r} between the bearing cage and Race2
CTHETAZ	Float, Torsional damping C_{θ_z} between the bearing cage and Race2

6.3 Roller bearing cage

The CAGE command in Figure **??** leads to the cage menu shown in Figure 6.30. An axial and lateral (in the circular direction) clearance type constraint is imposed between the individual rollers. The amount of this clearance is specified in AXIALCLEARANCE LATERALCLEARANCE, repectively.

A stiffness type connection is established between the cage and Race2 of the roller bearing. These stifnness values can be specified through KR, KZ, KTHETAR and KTHETAZ. Corresponding damping values are given by CR, CZ, CTHETAR and CTHETAZ.


MultyX.Edit.Connector.Cage
EXIT
QUIT

LATERALCLEARANCE

AXIALCLEARANCE

KR

KZ 0.0000000000e+000

KTHETAR

KTHETAZ 0.0000000000e+000

CR 0.0000000000e+000

CZ 0.0000000000e+000

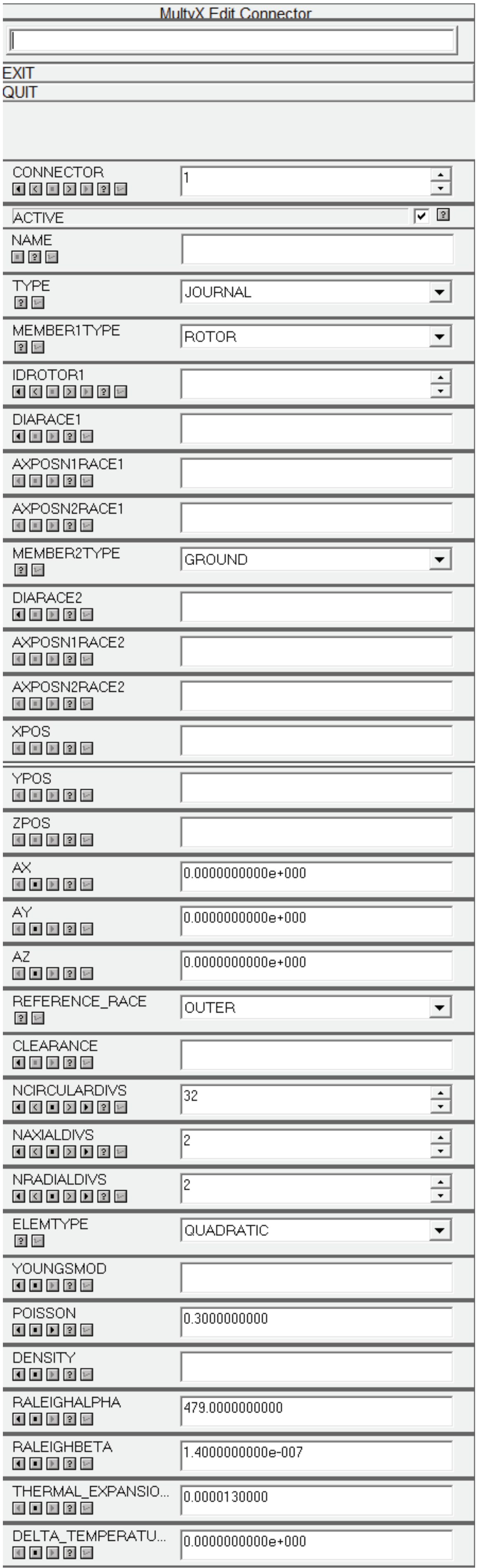
CTHETAR 0.0000000000e+000

CTHETAZ 0.0000000000e+000

Figure 6.30 The Roller bearing cage menu

6.4 Journal Bearings

When the JOURNAL bearing TYPE is selected within the CONNECTORS menu, the menu appears as shown in Figure 6.31. The journal bearing is modeled in a similar way to the roller bearing, except that instead of roller elements between the two races, a clearance is defined and contact between the outer and inner race is analyzed. The inputs in the journal bearing connectors menu can also be found in the connectors, material, and femodel menus/submenus of the roller bearing model. The CLEARANCE variable within the journal connectors menu is the only additional variable not found in the 3 roller bearing menus. CLEARANCE defines the radial clearance of the journal bearing between the inner and outer races. The contact pair for the contact analysis is automatically created and the grid is automatically defined.



CONNECTOR	1
ACTIVE	☑
NAME	
TYPE	JOURNAL
MEMBER1TYPE	ROTOR
IDROTOR1	
DIARACE1	
AXPOSN1RACE1	
AXPOSN2RACE1	
MEMBER2TYPE	GROUND
DIARACE2	
AXPOSN1RACE2	
AXPOSN2RACE2	
XPOS	
YPOS	
ZPOS	
AX	0.0000000000e+000
AY	0.0000000000e+000
AZ	0.0000000000e+000
REFERENCE_RACE	OUTER
CLEARANCE	
NCIRCULARDIVS	32
NAXIALDIVS	2
NRADIALDIVS	2
ELEMTYPE	QUADRATIC
YOUNGSMOD	
POISSON	0.3000000000
DENSITY	
RALEIGHALPHA	479.0000000000
RALEIGHBETA	1.4000000000e-007
THERMAL_EXPANSIO...	0.0000130000
DELTA_TEMPERATU...	0.0000000000e+000

6.5 Thrust Bearings

Transmission3D can model thrust bearings as either stiffness or roller type connectors. These two connectors are labeled THRUSTSTIFFNESSBRG and THRUSTROLLERBRG within the TYPE switch in the CONNECTORS menu. The connectors menu input fields change depending upon the type selected. Each of the two thrust bearings are described in the following two subsections.

6.5.1 Thrust Stiffness Bearing

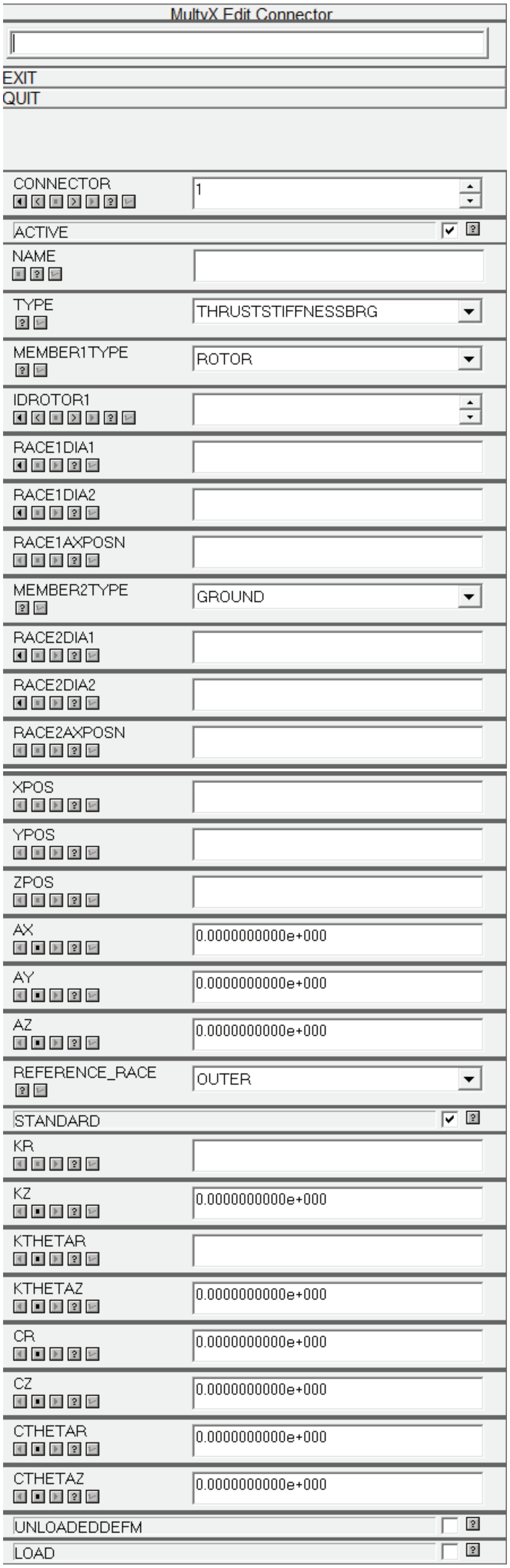
The thrust stiffness bearing CONNECTOR menu is shown in Figure 6.32. This connector type is similar to the standard stiffness connector described earlier, but the races are annular rings about the shaft rotational axis. The annular races are related by a stiffness matrix.

The thrust stiffness bearing connects two members in the same way as the standard stiffness connector type. The MEMBER1TYPE can be either a HOUSING OR ROTOR and the MEMBER2TYPE can be GROUND, HOUSING, or ROTOR.

The XPOS, YPOS, and ZPOS inputs define the origin of the thrust stiffness connector, while the AX, AY, and AZ inputs describe the direction of the unit vector oriented along the rotational axis of the shaft. RACE1AXIALPOSN and RACE2AXIALPOSN sets the locations of the two races along the shaft rotational axis relative to the connector origin. RACE1DIA1 and RACE2DIA1 sets the inner diameters of the first and second races, respectively. The RACE1DIA2 and RACE2DIA2 inputs set the outer diameters for the 1st and second annular races. The REVERENCE_RACE input allows the user to select either RACE1 or RACE2 to be the reference.

The stiffness of the thrust stiffness connector can be defined using one of three matrices: STANDARD, DIAGONAL, or FULL. The STANDARD checkbox enables the use of the standard stiffness matrix method. Using the standard matrix, KX = KY = KR and KTHETAX = KTHETAY = KTHETAR. KR, KZ, KTHETAR, and KTHETAZ are the required inputs for the standard stiffness matrix type. The DIAGONAL matrix is used by not selecting the STANDARD checkbox, and then selecting DIAGONAL from the MATRIXTYPE input field. The diagonal matrix consists of the 6 diagonal terms: KX, KY, KZ, KTHETAX, KTHETAY, and KTHETAZ. The FULL stiffness matrix is modeled by selecting FULL from the MATRIXTYPE switch. Upon selecting this option, the MATRIX submenu appears. The MATRIX menu consists of the four inputs shown in Figure 6.33. A 6x6 matrix can be defined using these menu inputs if modeling off-diagonal contributions is desired.

The damping contstant inputs available are in in the radial (CR), axial (CZ), radial rotational (CTHETAR), and axial rotational (CTHETAZ) directions, similarly to the standard spring stiffness contstants. The UNLOADEDDEFM and LOAD checkboxes can be used to define deformation of the bearing in the unloaded state and an external load at the bearing origin in the same way as described for the standard stiffness bearings previously.



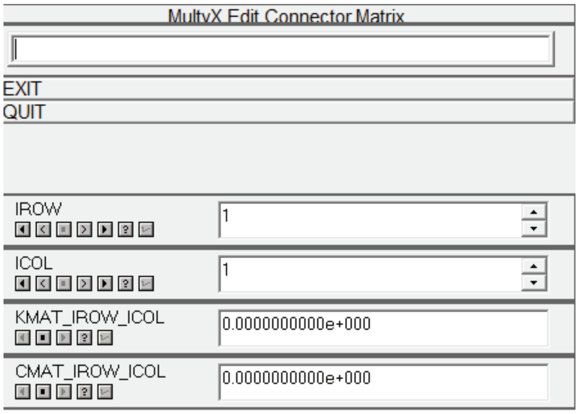
MultyX Edit Connector

EXIT

QUIT

CONNECTOR	1
ACTIVE	☑
NAME	
TYPE	THRUSTSTIFFNESSBRG
MEMBER1TYPE	ROTOR
IDROTOR1	
RACE1DIA1	
RACE1DIA2	
RACE1AXPOSN	
MEMBER2TYPE	GROUND
RACE2DIA1	
RACE2DIA2	
RACE2AXPOSN	
XPOS	
YPOS	
ZPOS	
AX	0.0000000000e+000
AY	0.0000000000e+000
AZ	0.0000000000e+000
REFERENCE_RACE	OUTER
STANDARD	☑
KR	
KZ	0.0000000000e+000
KTHETAR	
KTHETAZ	0.0000000000e+000
CR	0.0000000000e+000
CZ	0.0000000000e+000
CTHETAR	0.0000000000e+000
CTHETAZ	0.0000000000e+000
UNLOADEDDEFM	☐
LOAD	☐

Figure 6.32 The THRUSTSTIFFNESS bearing CONNECTOR menu.


MultyX Edit Connector Matrix
EXIT
QUIT

IROW: 1

ICOL: 1

KMAT_IROW_ICOL: 0.0000000000e+000

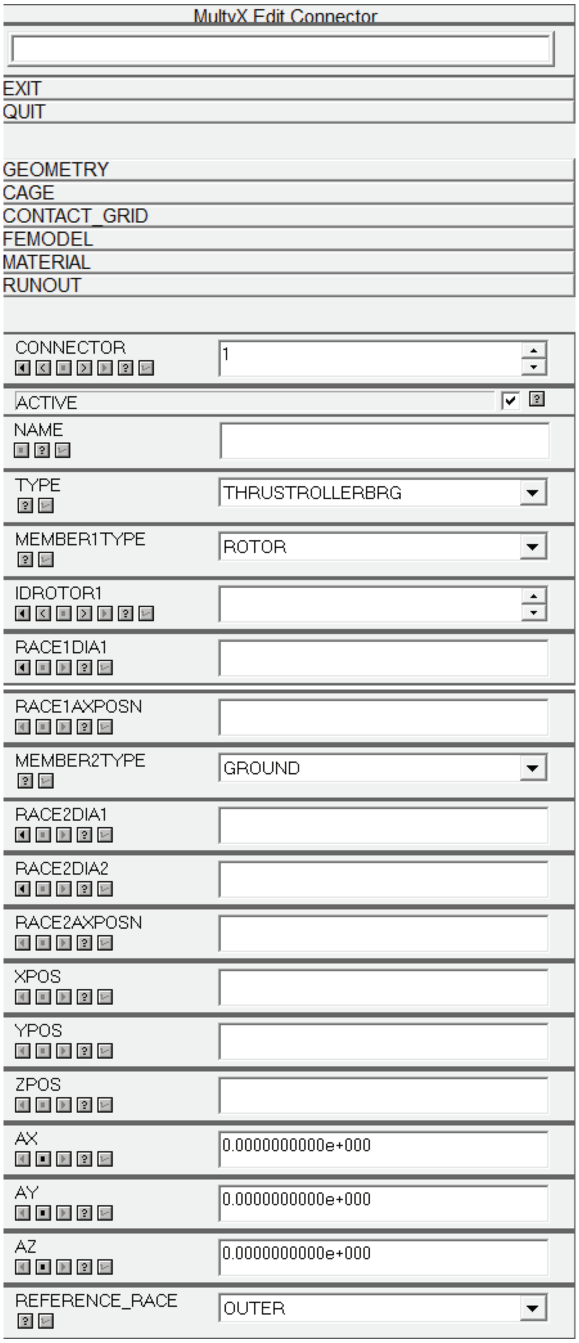
CMAT_IROW_ICOL: 0.0000000000e+000

Figure 6.33 The THRUSTSTIFFNESS bearing MATRIX menu.

6.5.2 Thrust Roller Bearing

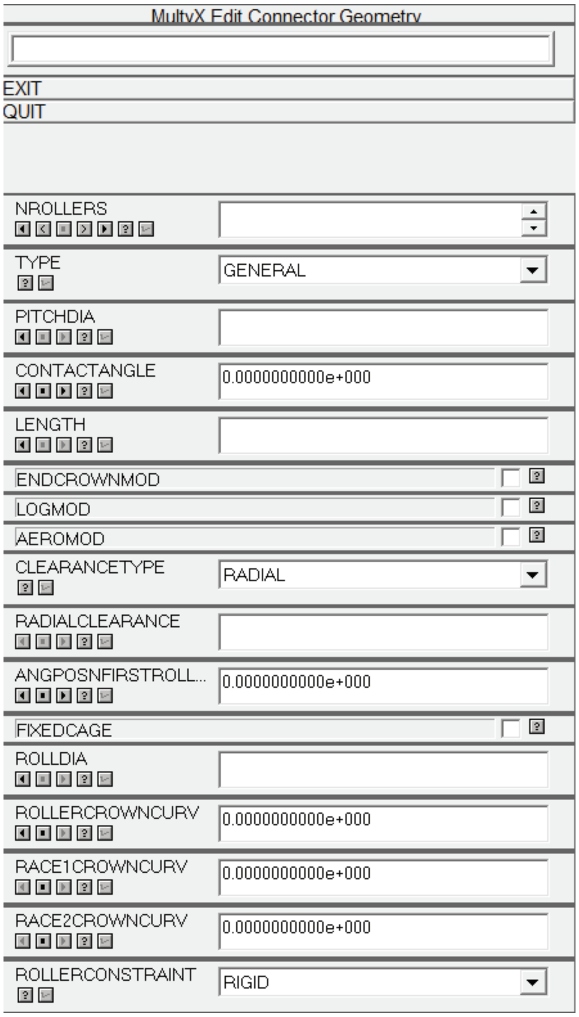
A roller thrust bearing can be modeled by selecting THRUSTROLLERBRG from the TYPE input in the CONNECTOR menu. Figure 6.34 shows the CONNECTOR menu inputs with the THRUSTROLLERBRG selected. The connector menu inputs for the thrust roller bearing are identical to the inputs described for the thrust stiffness bearing, with the exception of the stiffness, damping, unloaded deformation, and load inputs. The thrust roller bearing connector menu contains the same six submenus that were described in the roller bearing section. The CAGE, CONTACT_GRID, FEMODEL, MATERIAL, and RUNOUT menu inputs are identical to those presented previously.

The GEOMETRY menu inputs describe the thrust roller geometry. The GEOMETRY menu and the thrust roller bearing schematic are shown in Figures 6.35 and 6.36, respectively. The roller thrust bearing mesh generator automatically generates a tapered roller element, so that the roller is constrained in the radial direction. The geometry menu inputs for the thrust roller bearing are nearly identical to the inputs in the geometry menu for the general roller bearings. The thrust roller geometry menu does not include the UZ-CONSTRAINT, SAMELENGTHROWS, and NROWS inputs. A detailed description of each of the thrust roller geometry menu inputs is provided in Table 6.14.


MultyX Edit Connector
EXIT
QUIT
GEOMETRY
CAGE
CONTACT_GRID
FEMODEL
MATERIAL
RUNOUT

CONNECTOR	1
ACTIVE	☑
NAME	
TYPE	THRUSTROLLERBRG
MEMBER1TYPE	ROTOR
IDROTOR1	
RACE1DIA1	
RACE1AXPOSN	
MEMBER2TYPE	GROUND
RACE2DIA1	
RACE2DIA2	
RACE2AXPOSN	
XPOS	
YPOS	
ZPOS	
AX	0.0000000000e+000
AY	0.0000000000e+000
AZ	0.0000000000e+000
REFERENCE_RACE	OUTER

Figure 6.34 The THRUSTROLLER bearing CONNECTOR menu.



NROLLERS	
TYPE	GENERAL
PITCHDIA	
CONTACTANGLE	0.0000000000e+000
LENGTH	
ENDCROWNMOD	☐
LOGMOD	☐
AEROMOD	☐
CLEARANCETYPE	RADIAL
RADIALCLEARANCE	
ANGPOSNFIRSTROLL...	0.0000000000e+000
FIXEDCAGE	☐
ROLLDIA	
ROLLERCROWNCURV	0.0000000000e+000
RACE1CROWNCURV	0.0000000000e+000
RACE2CROWNCURV	0.0000000000e+000
ROLLERCONSTRAINT	RIGID

Figure 6.35 The THRUSTROLLER bearing GEOMETRY menu.

Table 6.14 Additional items for a THRUSTROLLERBRG TYPE connector.

Item	Description
NROLLERS	Integer, Number of rollers on the bearing
PITCHDIA	Float, Pitch diameter of the rollers
CONTACTANGLE	Float, Contact angle (Deg) at the rollers
LENGTH	Float, Length of the roller
ENDCROWNMOD	Boolean, Enables the end crown modification for the roller. The end crown modification is symmetric, and has a flat, unmodified length at the middle of the roller length. A crowning radius is applied at the ends of the roller length. Parameters are crown radius and flat length.
LOGMOD	Boolean, turns on the logarithmic modification for the roller. It takes only one parameter-the magnitude of the modification.
AEROMOD	Boolean, Turns on the ’Aero’ modification for the roller. The aero modification is symmetric, and has a flat unmodified length at the middle of the roller length. A crowning radius is applied at the ends of the roller length. The slope is discontinuous at the end of the flat for this modification. Parameters are crown radius, corner radius, and flat length.
CLEARANCE	Float, The radial or axial clearance at the rollers, depending upon the type selected.
ROLLDIA	Float, The diameter of the rollers
ANGPOSNFIRSTROLL	Float, The angular position (degrees) of the first roller. Setting this to zero places the center of the first roller at the positive x-axis.
FIXEDCAGE	Boolean, Enabling this feature causes the cage to remain stationary. This can be useful if precise location of the rollers is required.
OFFSET	Float, Axial offset of the roller
ROLLERCROWNCURV	Float, Crown curvature of the rollers
RACE1CROWNCURV	Float, Crown curvature of race 1 of the rollers
RACE2CROWNCURV	Float, Crown curvature of race 2 of the rollers
ROLLERCONSTRAINT	Switch, Controls the type of constraint that is applied to the base of the roller. RIGID: The base of the roller will be undeformed. FLEXIBLE: The base will be allowed to deform using a Fourier series in the circular direction and a plynomial series in the axial direction. Oly those terms in the series corresponding to rigid body motion will be constrained.

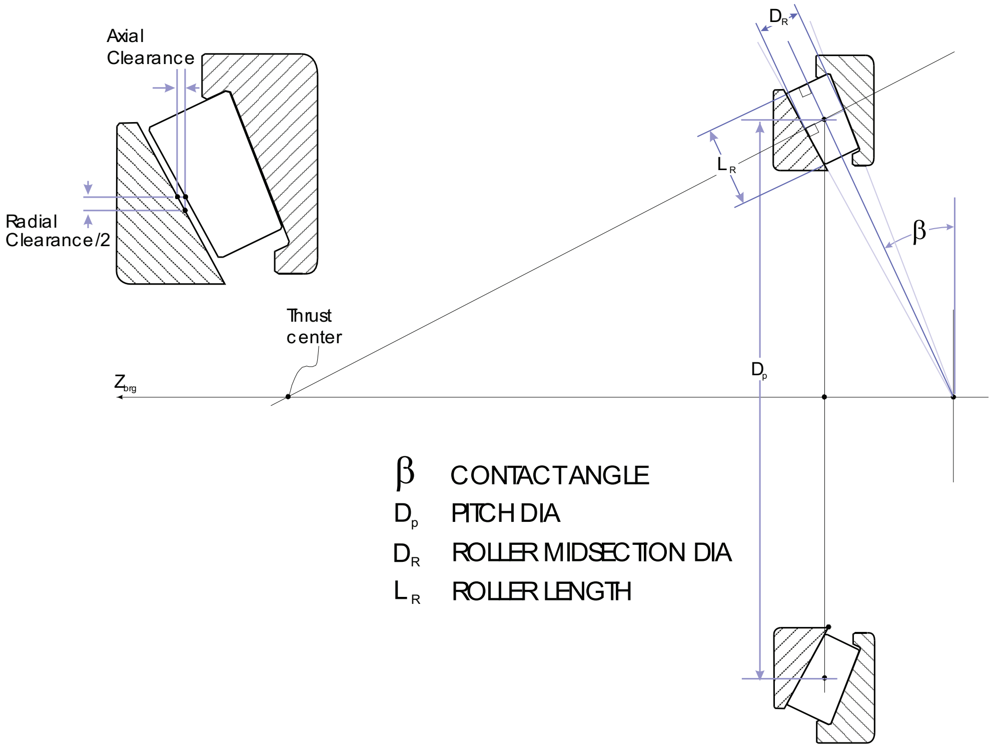

Axial Clearance
Radial Clearance/2
Thrust center
Z_{brg}
D_R
L_R
β
D_p
β CONTACT ANGLE
D_p PITCH DIA
D_R ROLLER MIDSECTION DIA
L_R ROLLER LENGTH

Figure 6.36 The THRUSTROLLER bearing schematic.

Table 6.15 The items that pertain to the spline option in the connector menu.

Item	Description
TYPE	Switch, Type of connector- Choices are STIFFNESS, ROLLER, INTERNALSPLINED and EXTERNALSPLINED
NSPLINES	Integer, Number of splines on the rim
CONTACTTYPE	Switch, Whether the contact at the spline is single sided or double sided
BACKLASH	Float, Amount of backlash(deg) at the splines
PRESSANGLE	Float, Pressure angle (deg) of the spline
WIDTH	Float, Width of the spline
HEIGHT	Float, Height of the spline
LENGTH	Float, Length of the spline
OFFSET	Float, Axial offset of the spline
EVEN	Boolean, Whether splines are evenly distributed
ANGPOSNFIRSTSPLINE	Float, Angular position (deg) of the first spline
NDIVSWIDTH	Integer, No. of elements along the width
NDIVSHEIGHT	Integer, No. of elements along the height
NDIVSLENGTH	Integer, No. of elements along the length
ELEMTYPE	Switch, Type of finite element
YOUNGSMOD	Float, Youngs modulus for the splines
POISSON	Float, Poissons ratio for the splines
DENSITY	Float, Density of the spline
RAYLEIGHALPHA	Float, Value of α in the equation C=α M+ β K
RAYLEIGHBETA	Float, Value of β in the equation C=α M+ β K

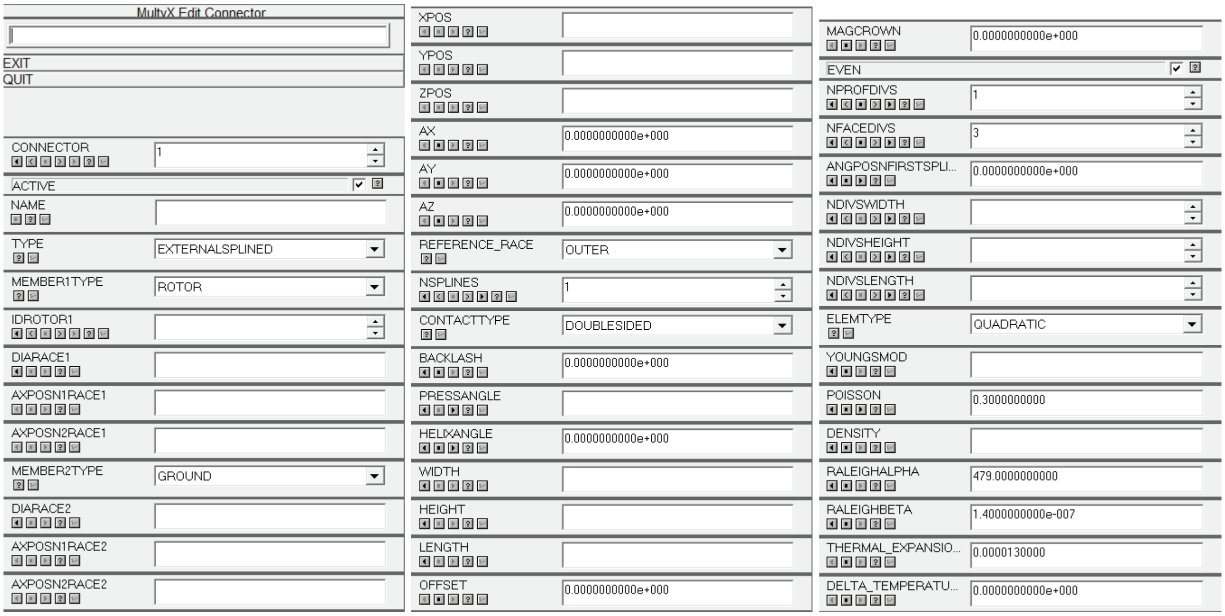
6.6 Spline connection

A spline type connector is modeled by setting the TYPE in the connector menu to EXTERNALSPLINED or INTERNALSPLINED. Figure 6.37 shows the items that pertain to the spline option in the connector menu.

The number of splines are specified in the NSPLINES item. The CONTACTTYPE switch specifies whether one sided or two sided contact will be enforced at the splines. If the two sided (DOUBLESIDED) contact type is selected the BACKLASH item pops up. A clearance at the splines can be introduced by specifying the angular backlash. The pressure angle for the spline is specified in the PRESSANGLE item. This is the angle between one side of the spline and the spline centerline (Figures 6.38 and 6.39). When this angle is zero, the two sides of the spline are parallel. The max value of this angle depends on the WIDTH and HEIGHT of the spline. The length of the spline in the axial direction is specified by LENGTH.

The offset in the axial direction is specified in OFFSET. When it is zero, the midsection of the spline coincides with the midsection of the overlapping part of the extents of the two races in the connector. When the EVEN flag is turned on, the splines are evenly distributed, otherwise the angular position of each spline may be specified. The angular position of the first spline is given by ANGPOSNFIRSTSPLINE item. A value of 0 will position the first spline centered at the X-axis. Table 6.15 describes the terms common to the splined internal and external splined menus. Figure 6.38 shows the spline connection parameters for internal spline type and Figure 6.39 shows the spline connection parameters for the external spline type.

MEMBER1TYPE must not be PINION for the spline connectors. Choosing PINION will raise an error during the model generation step.



MultyX Edit Connector

EXIT

QUIT

CONNECTOR	1
ACTIVE	☑
NAME	
TYPE	EXTERNALSPLINED
MEMBER1TYPE	ROTOR
IDROTOR1	
DIARACE1	
AXPOSN1RACE1	
AXPOSN2RACE1	
MEMBER2TYPE	GROUND
DIARACE2	
AXPOSN1RACE2	
AXPOSN2RACE2	
XPOS	
YPOS	
ZPOS	
AX	0.0000000000e+000
AY	0.0000000000e+000
AZ	0.0000000000e+000
REFERENCE_RACE	OUTER
NSPLINES	1
CONTACTTYPE	DOUBLESIDED
BACKLASH	0.0000000000e+000
PRESSANGLE	
HELIXANGLE	0.0000000000e+000
WIDTH	
HEIGHT	
LENGTH	
OFFSET	0.0000000000e+000
MAGCROWN	0.0000000000e+000
EVEN	☑
NPROFDIVS	1
NFACEDIVS	3
ANGPOSNFIRSTSPLI...	0.0000000000e+000
NDIVSWIDTH	
NDIVSHEIGHT	
NDIVSLENGTH	
ELEMTYPE	QUADRATIC
YOUNGSMOD	
POISSON	0.3000000000
DENSITY	
RALEIGHALPHA	479.0000000000
RALEIGHBETA	1.4000000000e-007
THERMAL_EXPANSIO...	0.0000130000
DELTA_TEMPERATU...	0.0000000000e+000

Figure 6.37 The Spline connection menu

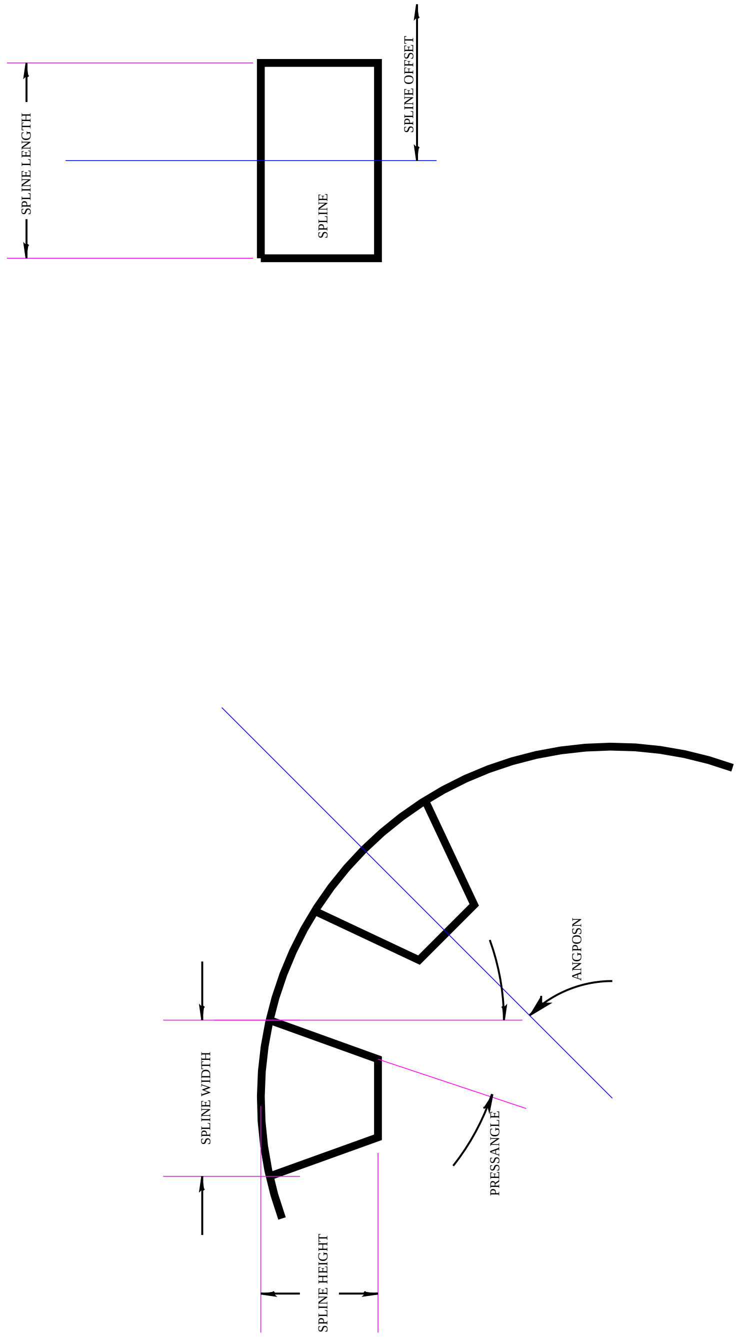

SPLINE LENGTH
SPLINE OFFSET
SPLINE
ANGPOSN
SPLINE WIDTH
PRESSANGLE
SPLINE HEIGHT

Figure 6.38 The Internal spline parameters

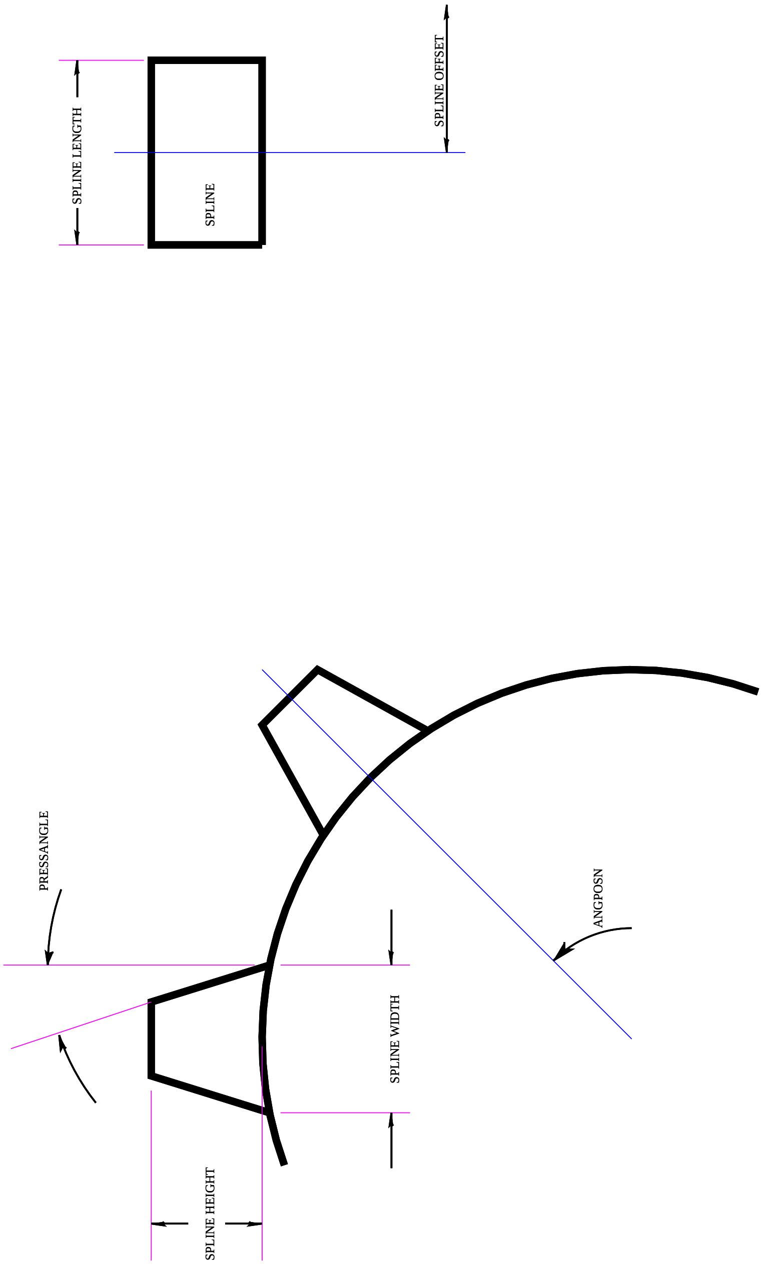

SPLINE LENGTH
SPLINE
SPLINE OFFSET
PRESSANGLE
ANGPOSN
SPLINE WIDTH
SPLINE HEIGHT

Figure 6.39 The External spline parameters

CHAPTER 7

GEAR PAIRS

For a *Transmission3D* package any two gears which are in contact are called a gear pair. Contact is enforced at gear pairs. A gear pair could be between 2 sun gears, a sun and a pinion, a sun and a ring gear, a ring and a pinion gear or between 2 pinions. If the ENABLEPAIRS menu in the EDIT menu (Figure 5.1) is turned on then the PAIRS button can be seen in the EDIT menu as shown in Figure 7.1. Figure 7.2 shows the pair menu for a SUN$-$SUN gear pair. Table 7.1 descibes the parameters for the SUN-SUN gear pair. The SUN-PINION gear pair menu is shown in Figure 7.3. Table 7.2 describes the parameters associated with the SUN-PINION gear pair. All other gear pair menu parameters are similar to those described in Table 7.1 and 7.2

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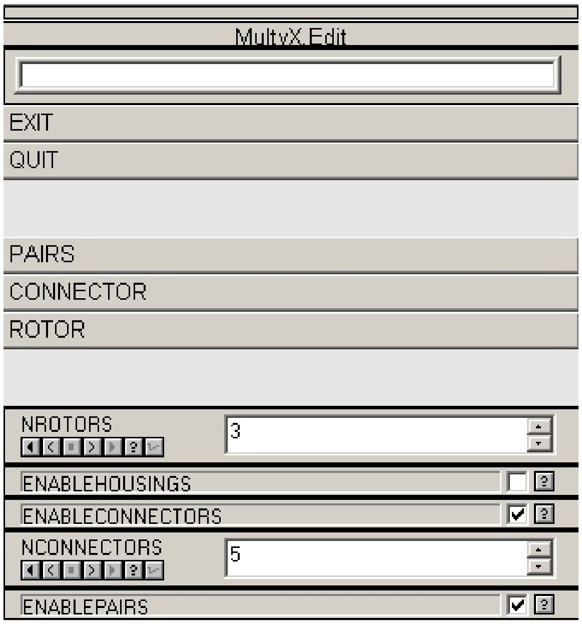

MultyX Edit
EXIT
QUIT
PAIRS
CONNECTOR
ROTOR

NROTORS 3

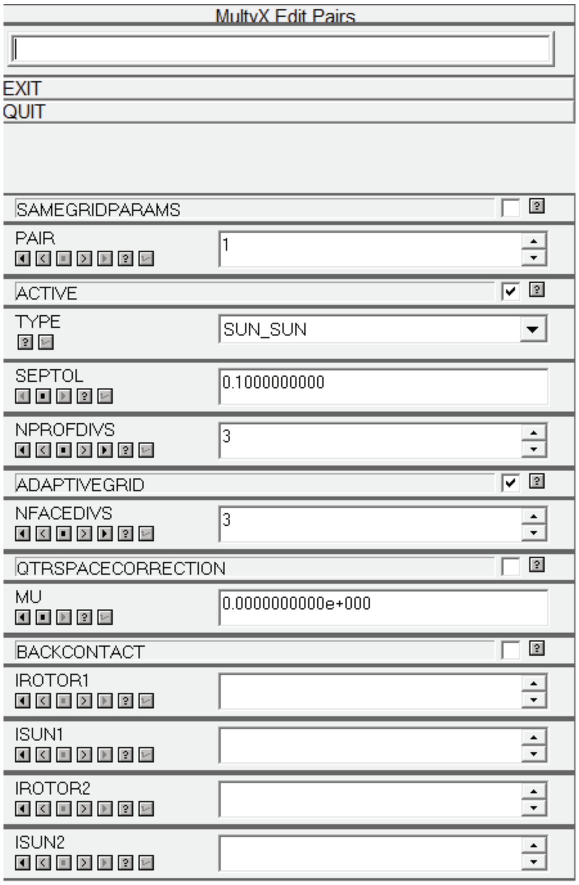
ENABLEHOUSINGS ☐

ENABLECONNECTORS ☑

NCONNECTORS 5

ENABLEPAIRS ☑

Figure 7.1 The EDIT menu with the ENABLEPAIRS menu turned on


MultyX Edit Pairs
EXIT
QUIT

SAMEGRIDPARAMS ☐

PAIR 1

ACTIVE ☑

TYPE SUN_SUN

SEPTOL 0.1000000000

NPROFDIVS 3

ADAPTIVEGRID ☑

NFACEDIVS 3

QTRSPACECORRECTION ☐

MU 0.0000000000e+000

BACKCONTACT ☐

IROTOR1

ISUN1

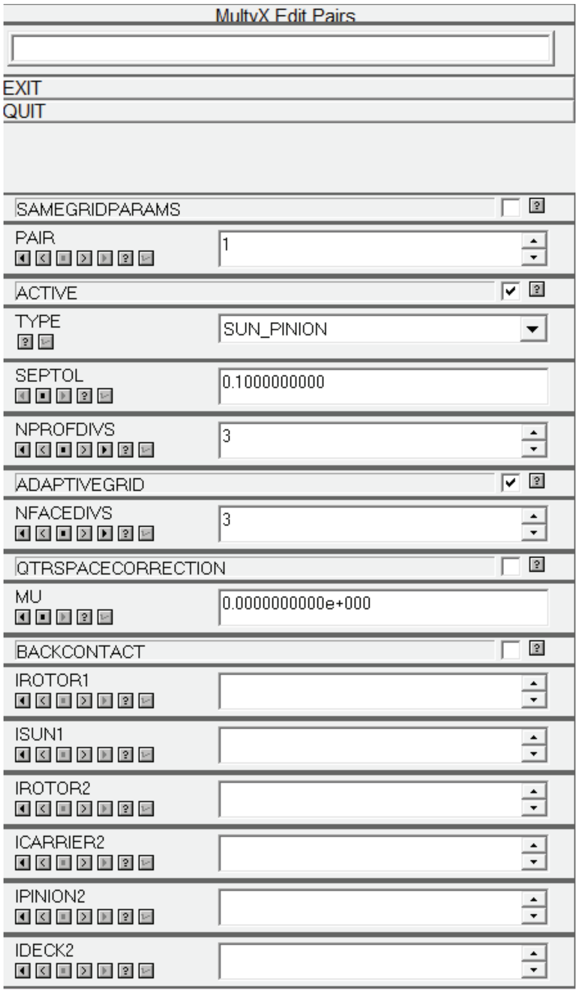
IROTOR2

ISUN2

Figure 7.2 The menu for SUN-SUN gear pair type

Table 7.1 The SUN-SUN gear pair menu

Item	Description
PAIR	Integer, Gear pair number
ACTIVE	Boolean, Turns the pair on and off
TYPE	Switch, Type of gear pair
SEPTOL	Float, Sets maximum surface separation for contact analysis
NPROFDIVS	Integer, Sets the number of divisions in the profile direction in the over the contact area. Total number of grids in the profile direction is 2*NPROFDIVS+1
ADAPTIVEGRID	Boolean, When enabled, the contact grid is sized adaptively in the profile direction
NFACEDIVS	Integer, Sets the number of divisions in the face direction in the over the contact area. Total number of grids in the profile direction is NFACEDIVS
QTRSPACECORRECTION	Boolean, If turn on, a quarter space correction will be carried out by mirror imaging loads about the free surfaces of a tooth. This will affect only the local deformation terms
MU	Float, Coefficient of Coulomb friction
BACKCONTACT	Boolean, Turning on enables contact on the coast side of the teeth will be considered. If enabled, contact grid parameters must be set separately for coast side contact
IROTOR1	Integer, Rotor for member 1 of the gear pair
ISUN1	Integer, Sun number for member1 of the gear pair
IROTOR2	Integer, Rotor for member 2 of the gear pair
ISUN2	Integer, Sun member for member 2 of the gear pair



SAMEGRIDPARAMS ☐
PAIR 1
ACTIVE ☑
TYPE SUN_PINION
SEPTOL 0.1000000000
NPROFDIVS 3
ADAPTIVEGRID ☑
NFACEDIVS 3
QTRSPACECORRECTION ☐
MU 0.0000000000e+000
BACKCONTACT ☐
IROTOR1
ISUN1
IROTOR2
ICARRIER2
IPINION2
IDECK2

Figure 7.3 The menu for SUN-PINION gear pair type

Table 7.2 The SUN−PINION gear pair menu

Item	Description
PAIR	Integer, Gear pair number
ACTIVE	Boolean, Turns the pair on and off
TYPE	Switch, Type of gear pair
SEPTOL	Float, Sets maximum surface separation for contact analysis
NPROFDIVS	Integer, Sets the number of divisions in the profile direction in the over the contact area. Total number of grids in the profile direction is 2*NPROFDIVS+1
ADAPTIVEGRID	Boolean, When enabled, the contact grid is sized adaptively in the profile direction
NFACEDIVS	Integer, Sets the number of divisions in the face direction in the over the contact area. Total number of grids in the profile direction is NFACEDIVS
QTRSPACECORRECTION	Boolean, If turn on, a quarter space correction will be carried out by mirror imaging loads about the free surfaces of a tooth. This will affect only the local deformation terms
MU	Float, Coefficient of Coulomb friction
BACKCONTACT	Boolean, Turning on enables contact on the coast side of the teeth will be considered. If enabled, contact grid parameters must be set separately for coast side contact
IROTOR1	Integer, Rotor for member 1 of the gear pair
ISUN1	Integer, Sun number for member1 of the gear pair
IROTOR2	Integer, Rotor for member 2 of the gear pair
ICARRIER2	Integer, Carrier number for member 2 of the gear pair
IPINION2	Integer, Pinion number for member 2 of the gear pair
IDECK2	Integer, Deck number for member 2 of the gear pair

CHAPTER 8

MODELING MANUFACTURING ERRORS

Transmission3D is capable of modeling the manufacturing errors listed in Table 8.1. In this section, we provide instructions for modeling each of these errors.

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Table 8.1 The Manufacturing Errors

Item	Description
Rotor Axis Error	Integer, Sun number for member1 of the gear pair
Rotor Misalignment	Integer, Rotor for member 2 of the gear pair
Tooth Spacing Error	The error in angular position of the tooth surfaces. Can be applied to sun, ring, or pinion type gears. Applied as a tooth surface transformation. Each side of the tooth is modeled independently.
Runout Error	The error in radial position of the tooth surfaces. Can be applied to sun, ring, or pinion. Applied as a tooth surface modifiction. Each tooth side surface is modeled independently.
Skew	Error in anglular position of gear tooth sides about radial axis in the plane perpendicular to the axis of rotation. The error for each side is modeled independently. Error is applied as a surface transformation. Can be applied to sun, ring, or pinion.
Out of Round Error	Roundness error of base circle. Can be applied to sun and ring gears.
Pinion Tooth Thickness Error	
Pinion Lead Error	
Carrier Pin Position Error	
Carrier Pin Misalignment	
Bearing Runout Error	Integer, Deck number for member 2 of the gear pair

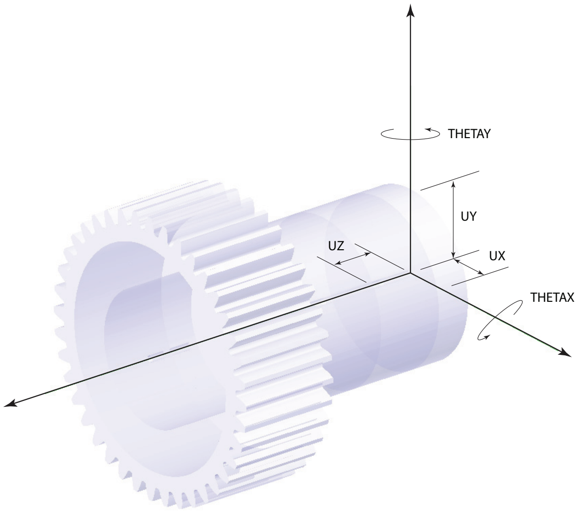
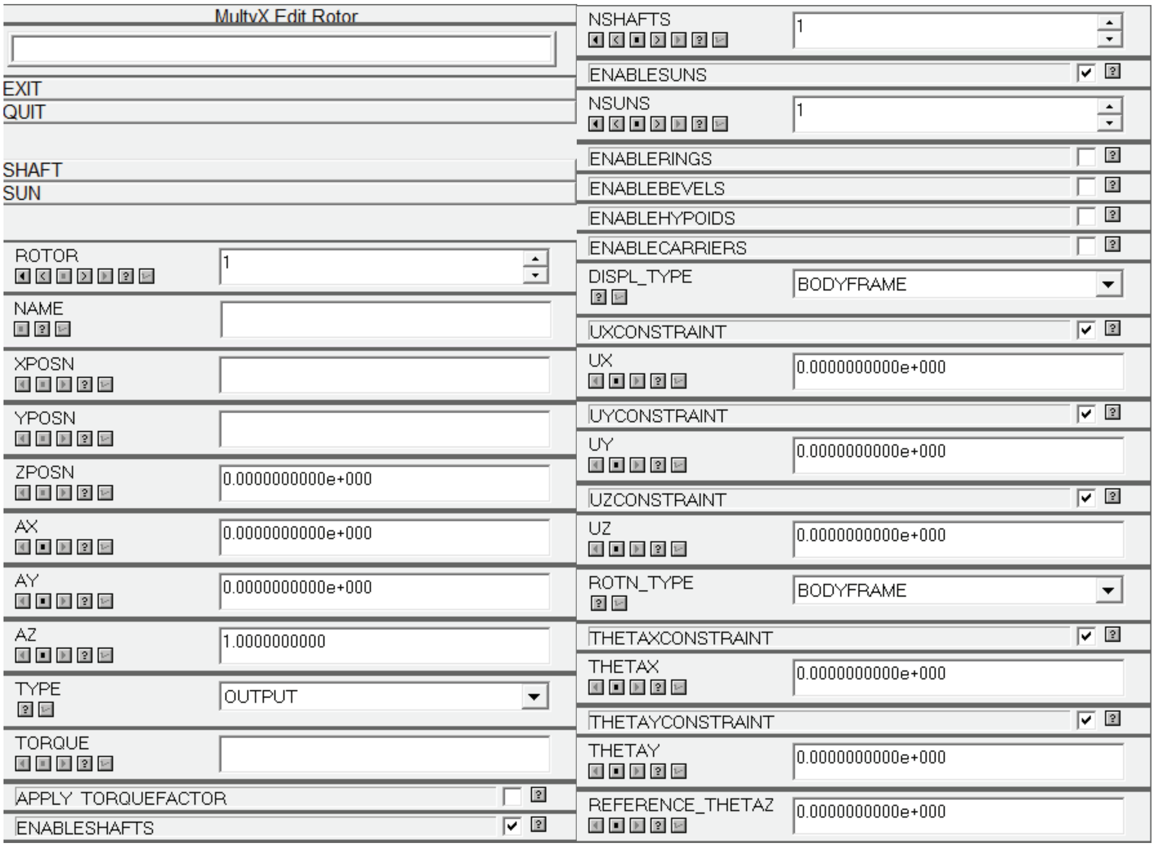


Figure 8.1 The rotor manufacturing errors.

8.1 Rotor Errors

The rotor manufacturing errors include the axis error and misalignment shown in Figure 8.1. The rotor axis error is the translational error in the shaft axis position in the x, y, and z directions. This error is modeled within the *Transmission3D* ROTOR menu (Figure 8.2) by selecting the UXCONSTRAINT, UYCONSTRAINT, and UZCONSTRAINT check boxes and entering the x, y, and z axis position errors in the UX, UY, and UZ input fields, respectively. The rotor axis misalignment is the axis position errors in the rotational directions about the x and y axis. These error values are entered within the THETAX and THETAY fields when THETAXCONSTRAINT and THETAYCONSTRAINT are checked.



MultyX Edit Rotor

ROTOR 1

NAME

XPOSN

YPOSN

ZPOSN 0.0000000000e+000

AX 0.0000000000e+000

AY 0.0000000000e+000

AZ 1.0000000000

TYPE OUTPUT

TORQUE

APPLY_TORQUEFACTOR ☐

ENABLESHAFTS ☑

NSHAFTS 1

ENABLESUNS ☑

NSUNS 1

ENABLERINGS ☐

ENABLEBEVELS ☐

ENABLEHYPOIDS ☐

ENABLECARRIERS ☐

DISPL_TYPE BODYFRAME

UXCONSTRAINT ☑

UX 0.0000000000e+000

UYCONSTRAINT ☑

UY 0.0000000000e+000

UZCONSTRAINT ☑

UZ 0.0000000000e+000

ROTN_TYPE BODYFRAME

THETAXCONSTRAINT ☑

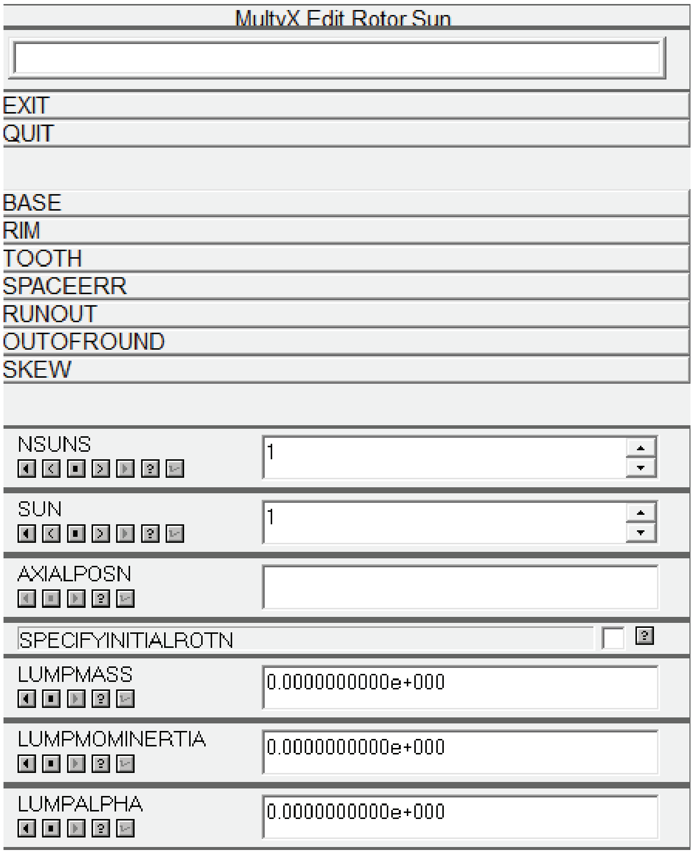
THETAX 0.0000000000e+000

THETAYCONSTRAINT ☑

THETAY 0.0000000000e+000

REFERENCE_THETAZ 0.0000000000e+000

Figure 8.2 The rotor menu.


MultyX Edit Rotor Sun
EXIT
QUIT
BASE
RIM
TOOTH
SPACEERR
RUNOUT
OUTOFROUND
SKEW
SPECIFYINITIALROTN

NSUNS 1

SUN 1

AXIALPOSN

LUMPMASS 0.0000000000e+000

LUMPMOMINERTIA 0.0000000000e+000

LUMPALPHA 0.0000000000e+000

Figure 8.3 The sun and ring menus.

8.2 Gear Errors

The gear manufacturing errors include the tooth spacing error, runout error, out of round error, and skew. These errors can be applied to any gear type (sun, ring, pinion) with the exception of the out of round error, which can only be applied to the sun and ring gear types. The SUN, RING, and DECK menus include the submenus used to model the gear manufacturing errors. The sun and ring menu structure is shown in Figure 8.3 and the pinion DECK menu is shown in Figur 8.4.

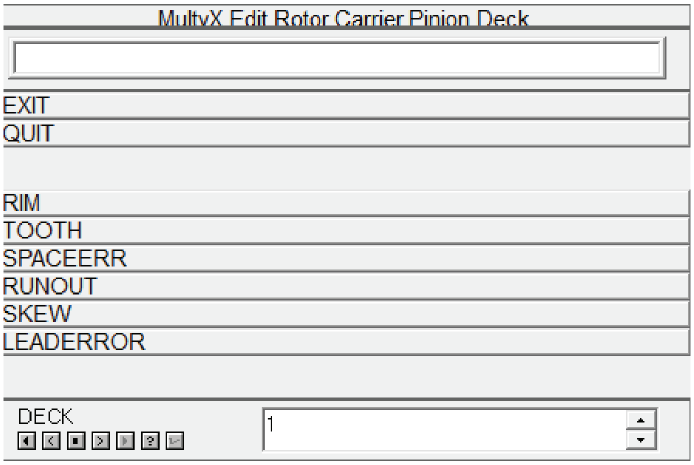

MultyX Edit Rotor Carrier Pinion Deck
EXIT
QUIT
RIM
TOOTH
SPACEERR
RUNOUT
SKEW
LEADERROR
DECK
1

Figure 8.4 The pinion deck menu.

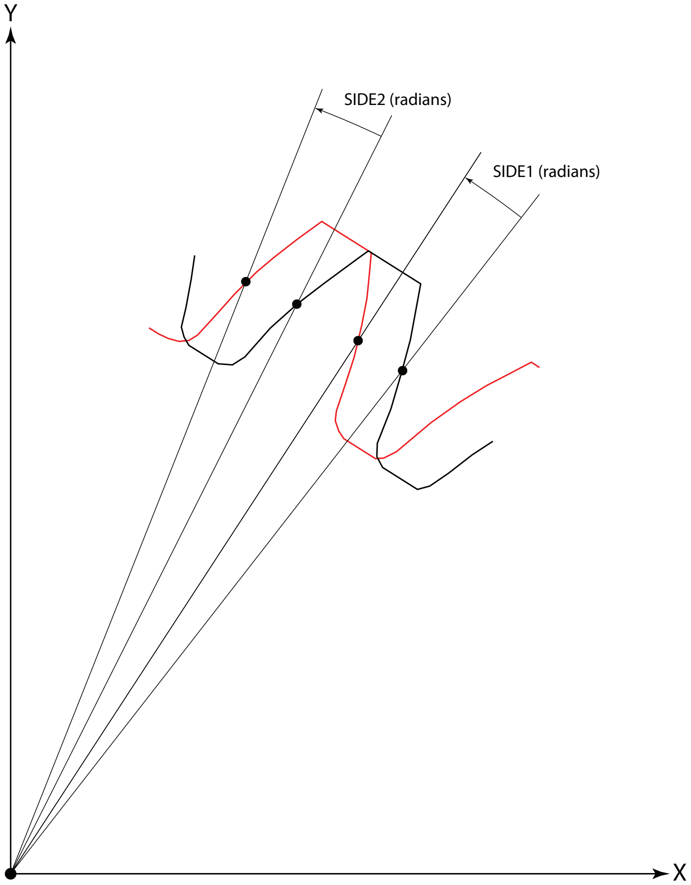


Figure 8.5 Tooth spacing error for external gears.

8.2.1 Tooth Spacing Error

The tooth spacing error is modeled within the SPACEERR submenu. This error specifies the difference in angular position between the actual point on a tooth surface and that point's theoretical angular position. The tooth spacing error is applied as a tooth surface modification so the entire surface is rotated by the error amount. The errors on the two sides of the tooth are independent, so an error input value can be entered for each side of the tooth (SIDE1 or SIDE2). Figures 8.5 and 8.6 show the definition of the spacing error graphically.

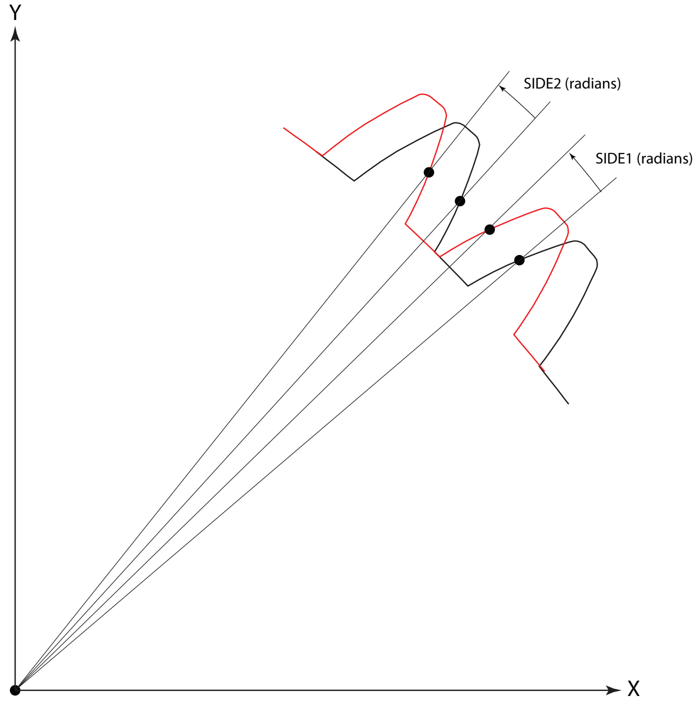

Y
X
SIDE2 (radians)
SIDE1 (radians)

Figure 8.6 Tooth spacing error for internal gears.

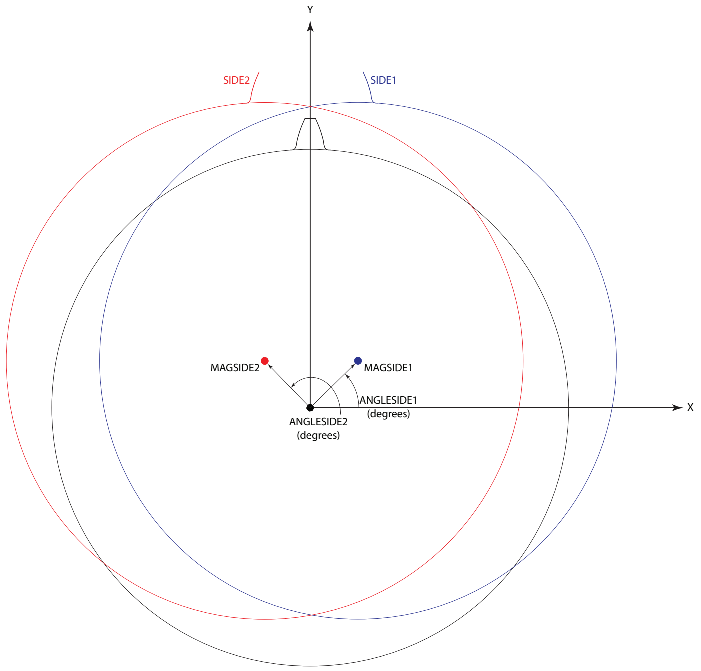


Figure 8.7 Runout error for external gears.

8.2.2 Runout Error

The runout error inputs are entered within the RUNOUT menu. The runout error specifies the error in the center point location between the theoretical involute and the actual involute. The error can be specified for each side of the involute independently. The runout error is defined by an angle (ANGSIDE1 and ANGSIDE2) and a magnitude (MAGSIDE1 and MAGSIDE2), as shown in Figures 8.7 through 8.9. The angle is measured using the right hand rule about the body reference frame for both the internal and external gear types. For pinions, the right hand rule is still used, but the x-axis from which the angle is measured is colinear with the position vector from the carrier rotor origin to the pinion center. The magnitude is the radial distance from the theoretical base circle center to the actual base circle center of the involute side, measured along the line defined by the angle of the corresponding involute side.

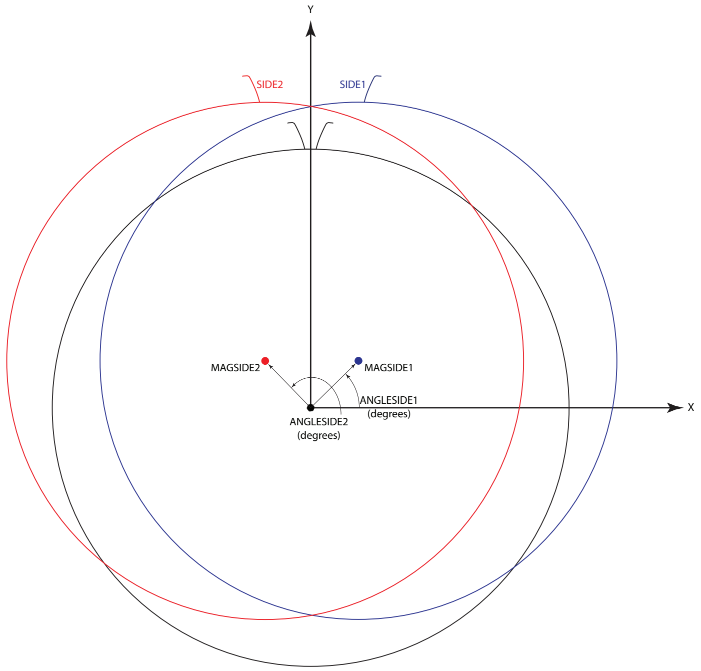

Y
SIDE2
SIDE1
MAGSIDE2
MAGSIDE1
ANGLESIDE1
(degrees)
X
ANGLESIDE2
(degrees)

Figure 8.8 Runout error for internal gears.

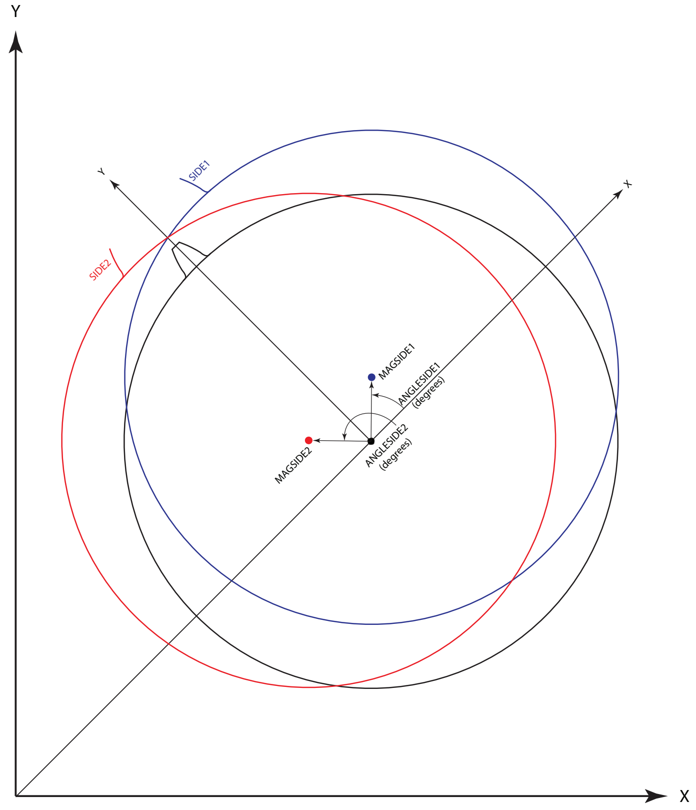

Y
SIDE1
Y
X
SIDE2
MAGSIDE1
ANGLESIDE1
(degrees)
ANGLESIDE2
(degrees)
MAGSIDE2
X

Figure 8.9 Runout error for pinions.

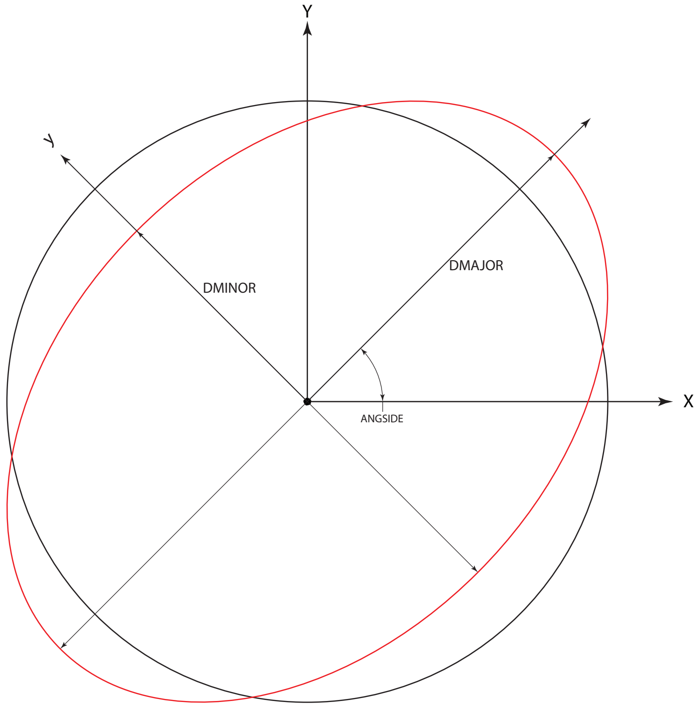


Figure 8.10 Out of round error.

8.2.3 Out of Round Error

The out of round error is modeled within the OUTOFROUND submenu, located within the SUN and RING menus. The out of round error models the error in the shape of the pitch circle of the gear tooth. The out of round error can be specified for each side of the gear tooth independently, with 2 input parameters required for each side (MAGSIDE and ANGSIDE). The MAGSIDE parameters specifies the magnitude of the error and is equal to one fourth of the difference between the diameter of the major axis and the diameter of the minor axis of the the pitch ellipse. The ANGSIDE parameter specifies the angle between the rotor reference frame's x-axis and the major axis of the pitch ellipse. Figure 8.10 shows the definition of the out of round error and the input parameters graphically.

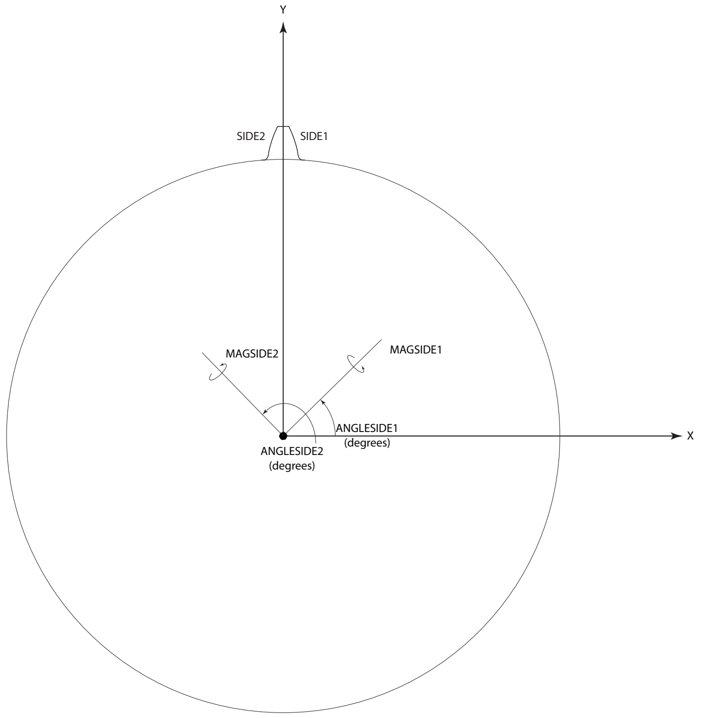


Figure 8.11 Skew error.

8.2.4 Skew

The fourth gear manufacturing error capable of being modeled in *Transmission3D* is the skew error of the gear. The skew error is the rotational error of the gear about an axis in the plane perpendicular to the gear rotational axis. The MAGSIDE and ANGLESIDE input parameters are available for each side of the gear tooth, allowing each side of the gear tooth to have a separate skew error. The ANGLESIDE input specifies the angle of the skew axis relative to the x-axis of the rotor reference frame. MAGSIDE defines the angle by which the gear tooth side is rotated about the skew axis. Figure 8.11 shows the definition of the skew error inputs graphically and Figure 8.12 shows an example of a gear where both sides of the gear teeth are skewed about the x-axis of the rotor reference frame by 10 degrees.

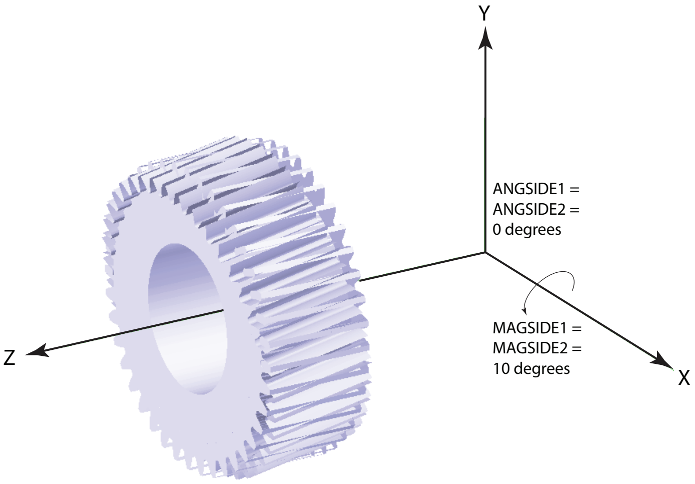
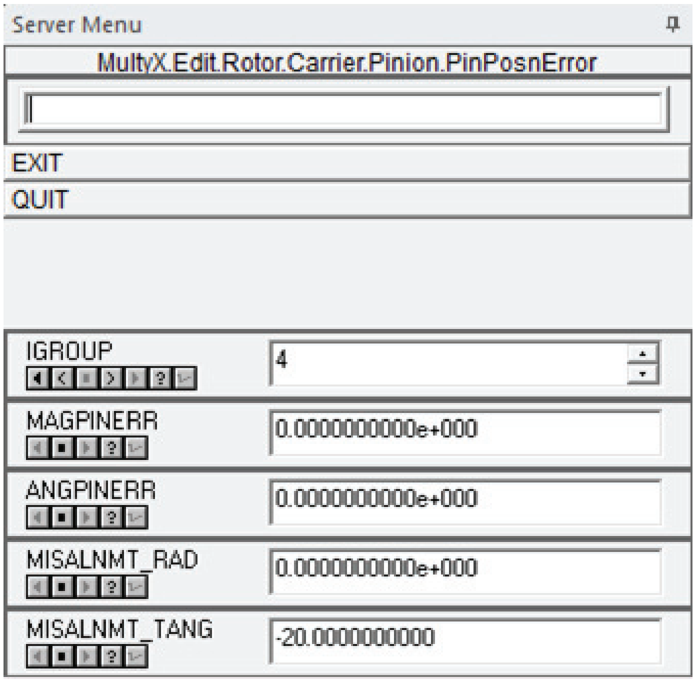

Y
ANGSIDE1 =
ANGSIDE2 =
0 degrees
MAGSIDE1 =
MAGSIDE2 =
10 degrees
Z
X

Figure 8.12 Skew error.



IGROUP 4

MAGPINERR 0.0000000000e+000

ANGPINERR 0.0000000000e+000

MISALNMT_RAD 0.0000000000e+000

MISALNMT_TANG -20.0000000000

Figure 8.13 PINPOSNERROR menu and tangential misalignment.

8.3 Carrier Pin Errors

Carrier pin position error and misalignment are modeled within the PINERROR submenu shown in Figure 8.13. The pin error shifts the pin axis in the plane perpendicular to the pinion rotational axis, and is defined by a vector. The vector angle is entered into the ANGPINERR input and the magnitude is defined by the MAGPINERR input. Figure 8.14 shows the definition of the pin position error inputs. Notice the position vector angle is defined relative to the axis that is colinear with the pinion center distance vector, similarly to that of the runout error for pinions.

The remaining two inputs of the PINERROR menu, MISALNMT_RAD and MISALNMT_TANG, define the radial and tangential angular misalignment angles, respectively. The radial misalignment is defined as the angle that the pinion is rotated about the axis colinear with the center distance vector of the pinion. The misalignment angle is measured from the radial position vector axis of the pinion and the angle is positive following the right hand rule about the rotor rotational axis. The tangential misalignment angle (MISALNMT_TANG) is the angle about the axis +90 degrees from the pinion position vector axis, following the right hand rule about the positive z-axis of the carrier. The tangential axis is positive pointing in the direction of positive rotation of the carrier. The angle of MISALNMT_TANG is positive following the right hand rule about the tangential axis. Figures 8.15 and 8.16 show the grahpical definition of the two misalignment parameters.

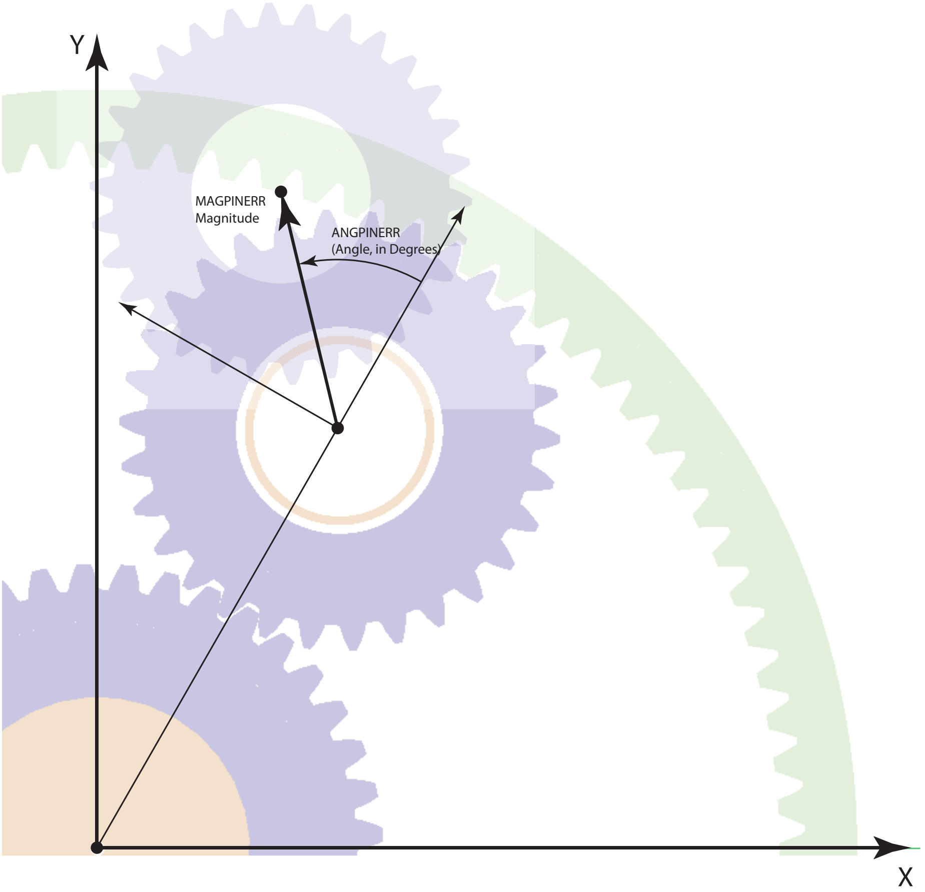

Y
MAGPINERR
Magnitude
ANGPINERR
(Angle, in Degrees)
X

Figure 8.14 Pin position error angle and magnitude.

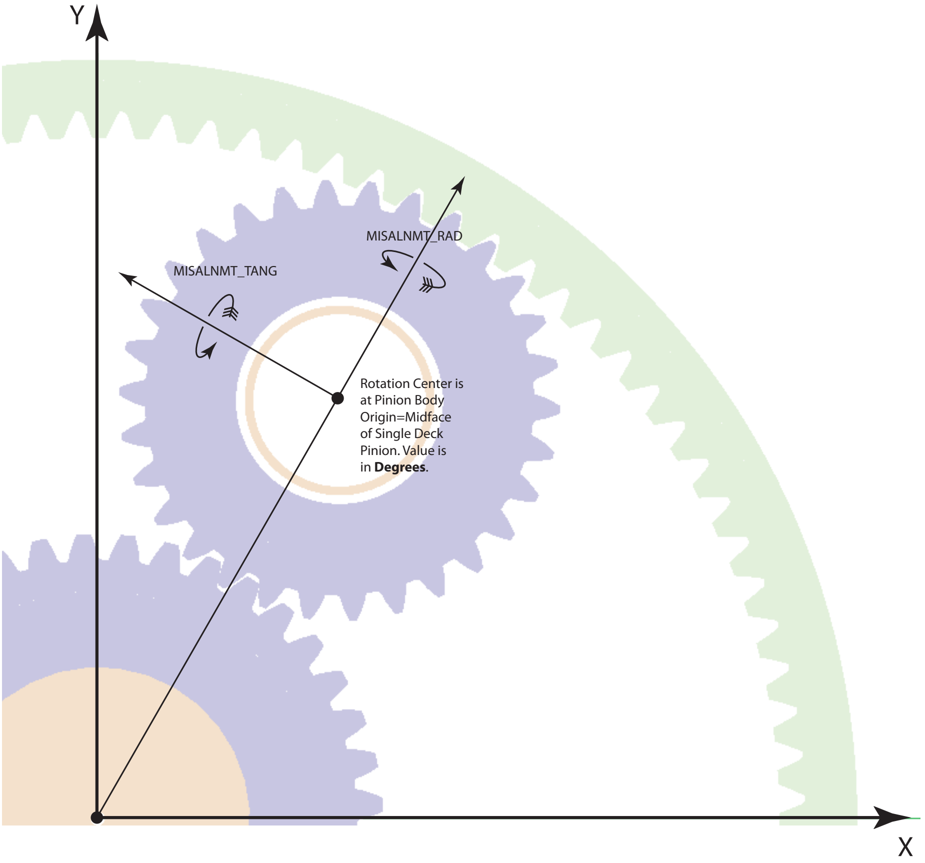

Y
MISALNMT_RAD
MISALNMT_TANG
Rotation Center is at Pinion Body Origin=Midface of Single Deck Pinion. Value is in **Degrees**.
X

Figure 8.15 Tangential and radial pinion misalignment.

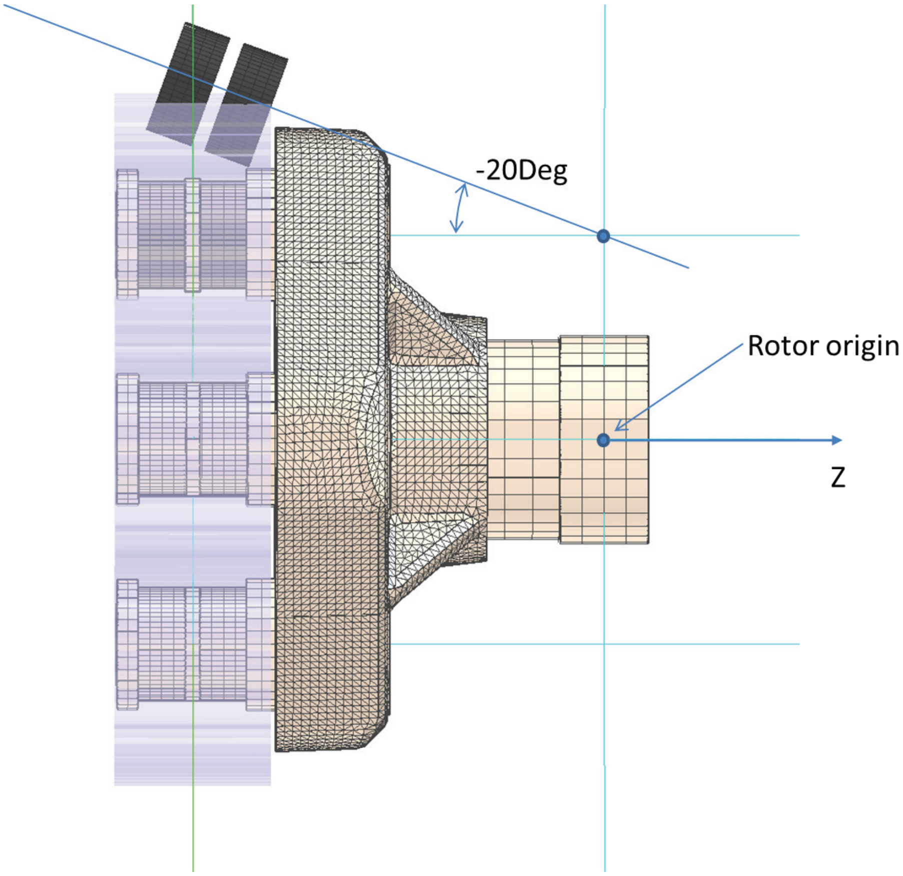

-20Deg
Rotor origin
Z

Figure 8.16 Tangential pinion misalignment.

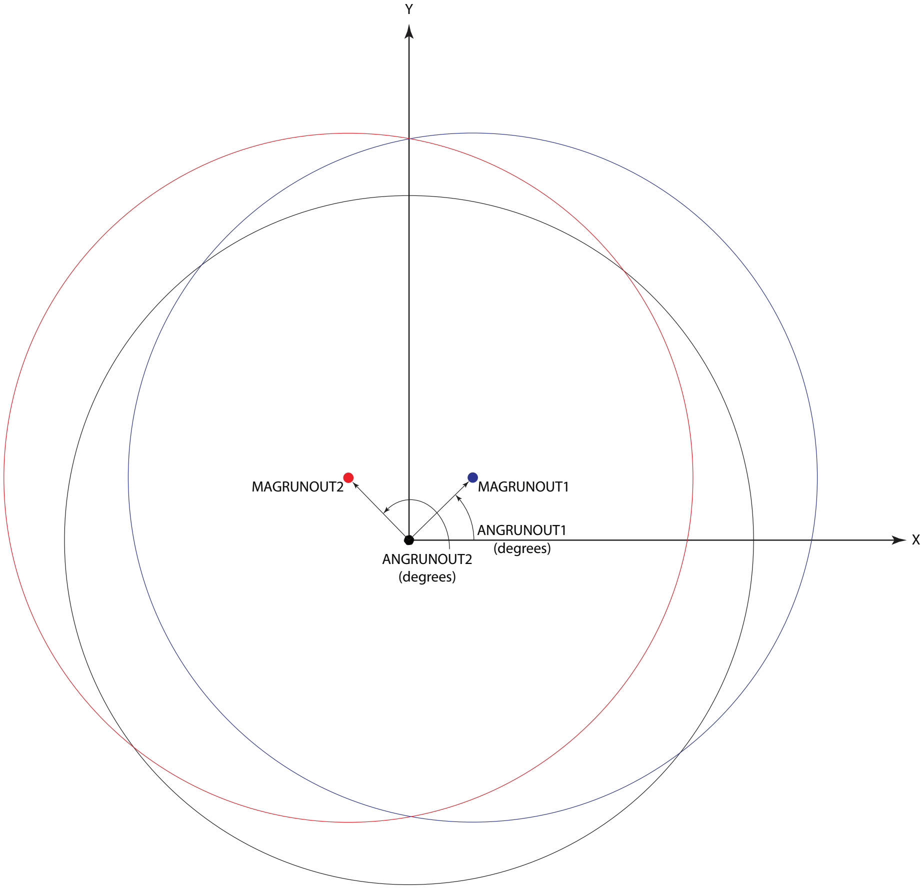


Figure 8.17 Bearing Runout Error.

8.4 Bearing Errors

The bearing runout error is modeled within the RUNOUT submenu of the BEARING menu when the bearing TYPE set to ROLLERS. The bearing runout error is similar to that of the gear runout errors, except that instead of modeling each tooth side independently, each bearing race can have a different runout error. The runout error for each race is defined by a runout angle (ANGRUNOUT) and magnitude (MAGRUNOUT). The runout angle is measured relative to the bearing x-axis, with the positive direction following the right hand rule about the bearing rotational axis. Figure 8.17 shows the bearing runout error inputs graphically.

CHAPTER 9

RUNNING AN ANALYSIS

The analysis is started by using STARTANAL command in the main menu.

Before starting an analysis, sensor locations have to be set up to measure stress and loads in the model. This is done through the SURFGAGES, FEPROBES and LOADSENSORS commands in the main menu. Additional analysis parameters and settings are controlled through the SETUP command.

9.1 Surface gages

A surface gage is used to measure the critical stress along tooth surfaces. The reading of each gage is the most critical stress measured over a user defined range of teeth, profile, face and depth along a specific surface.

Figure 9.1 shows the Surface Gage setup menu. The number of gages NGAGES has to be entered first. Then the gage number for a particular gage can be entered into the GAGE box, and the gage information can be typed into the remaining boxes. For each gage, the BODY item selects which of the individual components in the system the gage is attached to. For a 3D planetary analysis, the number of bodies depends upon the planetary system. Each rotor is a separate body. Also each pinion is a separate body. For instance a body member shown as PINION_2_1_1_2 would be the pinion attached to rotor2, on carrier1, and belonging to group2.

After the Body is selected, the surface on which the gage should be attached should be selected. The gear teeth typically have four surfaces. SURFACE1 and SURFACE2 cover the entire involute and fillet areas of the two sides Side 1 and Side 2, respectively, of the teeth. FILLET1 and FILLET2 cover only the fillet region of Side 1 and Side 2, respectively. For instance a pinion surface shown by SURF_2_1 would be the surface1 of the deck2 of the pinion selected in the BODY menu. If splines are used as bearing connections, then there will be two more surfaces in the SURFACE menu, SPLINESURF1 and SPLINESURF2, which are the two sides of the spline teeth.

When there are multiple copies of a surface on a body, each individual copy of that surface is called an instance of that surface, and is given a unique instance number. In the case of gear tooth surfaces, the instance number is the same as the tooth number. The parameters TOOTHBEGIN and TOOTHEND define a range

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of teeth over which the gages will be placed. The reading of the gage is the stress at the most critical tooth. If the value of TOOTHBEGIN is greater than TOOTHEND, then the search range will wrap around the last tooth.

There are two parameters that identify a point on a surface. We refer to these two parameters as S which varies in the profile direction, and T which varies in the face width direction.

The profile parameter S increases from fillet to the tip on Side 1 of a tooth, and from the tip to the fillet on Side 2, as shown in Appendix A. The parameters SPROFBEGIN and SPROFEND define a range over which the stress will be calculated. These are in surface local units as shown in Appendix A. The GAGE will read out the critical value of stress in this range. The NUMSPROF parameter controls how many search points should be used over this range.

The face parameter T varies from -1.0 to $+1.0$ over the face of the tooth. The face width range parameters TFACEBEGIN, control TFACEEND range over which the search is carried out, and NUMTFACE controls the number of search points within this range.

The DEPTHBEGIN, DEPTHEND and NUMDEPTH parameters extend the search range to a number NUMDEPTH of points ranging in depth from DEPTHBEGIN to DEPTHEND below the surface. This is an expensive computation, and should not be used unless necessary. The surface gage will measure the stress at the critical depth. The depth is in physical length units.

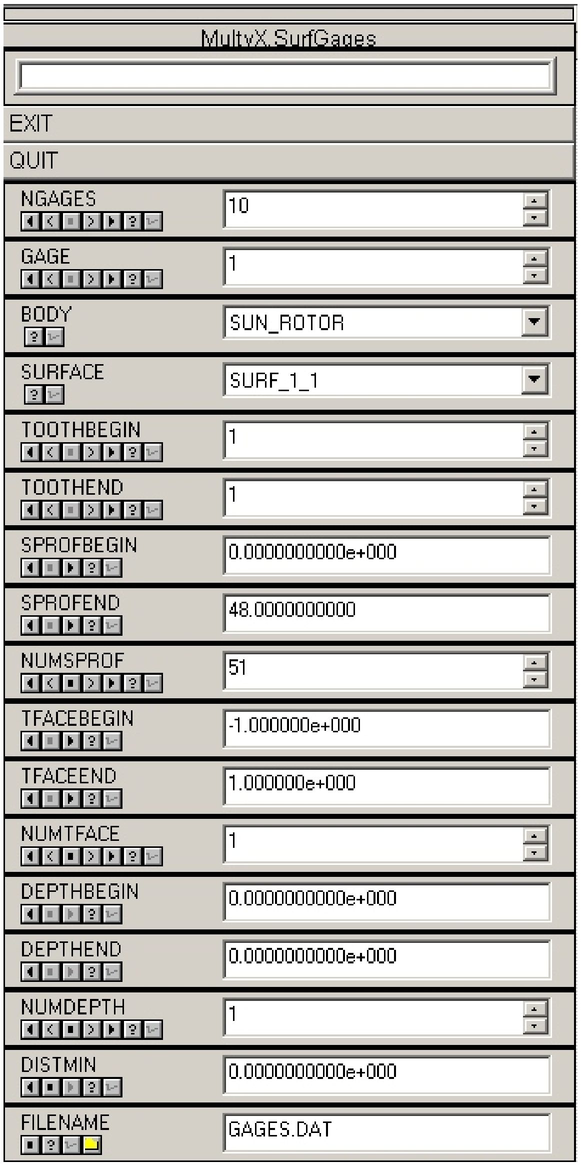
Because finite element stresses computed very close to the highly concentrated contact loads can have a large amount of error, we need a way to screen out points that are too close. The parameter DISTMIN is the minimum allowed distance of a stress calculation point from a contact point. Stresses will not be calculated at any point whose distance from a contact point is less than this value. This distance is in physical length units.

During the analysis, all the surface gage readings are written to a file called `GAGES.DAT`. Each row in this file corresponds to a time instant. The first column in the file contains the value of the time. The remaining columns contain the readings of the surface gages. There are four columns of data for each gage. The first column for a gage contains the critical maximum principal normal stress (s_1) over its search range. The second column contains the value of the critical minimum principal normal stress (s_3). The third column contains the critical maximum shear stress (τ_{max}), and the fourth column contains the critical Von Mises' shear stress (s_{vm}). The columns are separated by tabs.

9.2 Finite element probes

Finite Element Probes can be used to output stresses at a particular point when its element number and local coordinates are known. The Element numbering used in the gear tooth finite element meshes is shown in Appendix A. Figure 9.2 shows the finite element probe input menu. The BODY parameter selects the particular body or component to be probed. Each body can have many finite element meshes. The MESH parameter selects which finite element mesh should be probed. There may be many copies or instances of the finite element mesh. Each copy is given an instance number. In the case of a gear tooth mesh, this instance number is the same as the tooth number. Each shaft segment is a separate mesh member. The TOOTH parameter selects the instance number. The ELEM parameter selects the finite element number within the mesh. The XI, ETA and ZETA values are the local coordinates within the finite element. XI, ETA and ZETA vary between -1 and $+1$ over the element. Appendix A shows the orientation of the local coordinate axes for each finite element in the various mesh templates.

The COMPONENT parameter selects which stress component should be measured by the probe. Available options are Maximum principal normal stress (s_1), minimum principal normal stress (s_3), maximum shear stress (τ_{max}), Von Mises' octahedral shear stress (s_{vm}) and the displacement magnitude (u). The data measured by the finite element probes is written to a file called `PROBES.DAT`. The data file has a row for each time instant. The first column contains the value of time. Each subsequent column contains the readout of an individual probe.



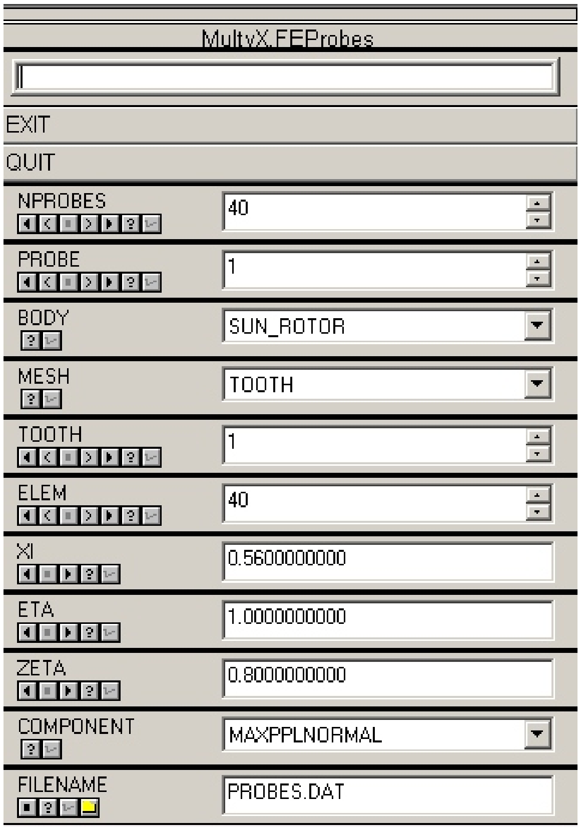
MultyX.SurfGages

EXIT

QUIT

NGAGES	10
GAGE	1
BODY	SUN_ROTOR
SURFACE	SURF_1_1
TOOTHBEGIN	1
TOOTHEND	1
SPROFBEGIN	0.0000000000e+000
SPROFEND	48.0000000000
NUMSPROF	51
TFACEBEGIN	-1.000000e+000
TFACEEND	1.000000e+000
NUMTFACE	1
DEPTHBEGIN	0.0000000000e+000
DEPTHEND	0.0000000000e+000
NUMDEPTH	1
DISTMIN	0.0000000000e+000
FILENAME	GAGES.DAT

Figure 9.1 The surface gage menu

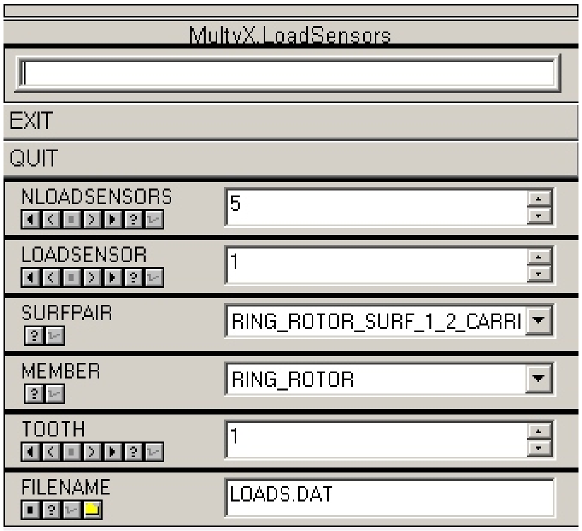

MultyX.FEProbes
EXIT
QUIT

NPROBES	40
PROBE	1
BODY	SUN_ROTOR
MESH	TOOTH
TOOTH	1
ELEM	40
XI	0.5600000000
ETA	1.0000000000
ZETA	0.8000000000
COMPONENT	MAXPPLNORMAL
FILENAME	PROBES.DAT

Figure 9.2 The finite element probe menu

9.3 Load sensors

Load sensors are used to measure the contact loads generated at the contact surfaces. Figure 9.3 shows the load sensor menu used to set up the sensors. The SURFPAIR item selects the contact surface pair for which the contact load is of interest. Each surface pairing has two contacting members or bodies. The MEMBER parameter selects one of these two bodies, and the TOOTH item selects the individual surface instance number within that body. The outputs of all the sensors are put into a file called `LOADS.DAT`. This file has one row for each instant of time. The first column contains the time. Each subsequent column contains the reading of one load sensor.



NLOADSENSORS 5

LOADSENSOR 1

SURFPAIR RING_ROTOR_SURF_1_2_CARRI

MEMBER RING_ROTOR

TOOTH 1

FILENAME LOADS.DAT

Figure 9.3 The load sensor menu

9.4 Specifying a contact grid

Figure 9.4 shows a computational grid that has been set up in the contact zone of a gear tooth. The entire face width of the tooth is divided into $2N + 1$ slices. N is a user selectable quantity (NFACEDIVS in Figure 9.9). If ζ is a parameter that goes from -1 at one end of the face width of a tooth to $+1$ at the other end, then the thickness of each slice in the ζ parameter space is $\Delta\zeta = 2/(2N + 1)$. For each slice $j = -N : +N$, a cross section of the tooth is taken at the middle of the slice, and a point is located on this slice that approaches the surface of the mating tooth the closest. This selection is carried out using the undeformed geometry. If the separation between the two gears at this closest point is larger than a user selectable separation tolerance (SEPTOL in Figure 9.9), then the entire gear slice is eliminated from further consideration. Otherwise, a set of grid cells identified by the grid cell location indices $(i, j), i = -M : M$ is set up centered around this closest point of slice j. The number M (NPROFDIVS in Figure 9.9) is user selectable. The dimension of the grid cells in the profile direction Δs (DSPROF in Figure 9.9) is also user selectable. Here s is the curve length parameter measaured along the profile.

The number M is referred to as the number of grid cells in the profile direction (NPROFDIVS), and N is referred to as the number of grid cells in the face width direction (NFACEDIVS). Δs is referred to as the width of the grid cell in the profile direction (DSPROF). The width of the grid is $(2M + 1)\Delta s$. Choosing the correct width is crucial in obtaining correct contact pressures. Using too wide a grid for a fixed M can result in loss of resolution, because only the center grid cell will end up carrying all the load (Figure 9.5). If the grid is too narrow, then the contact zone will get truncated, causing artificially high contact pressures at the edges of the grid (Figure 9.6). If the grid size is correct, a variation of contact pressure similar to that in Figure 9.7 should be obtained.

Figure 9.8 shows an example of a contact grid set up on a pair of contacting teeth.

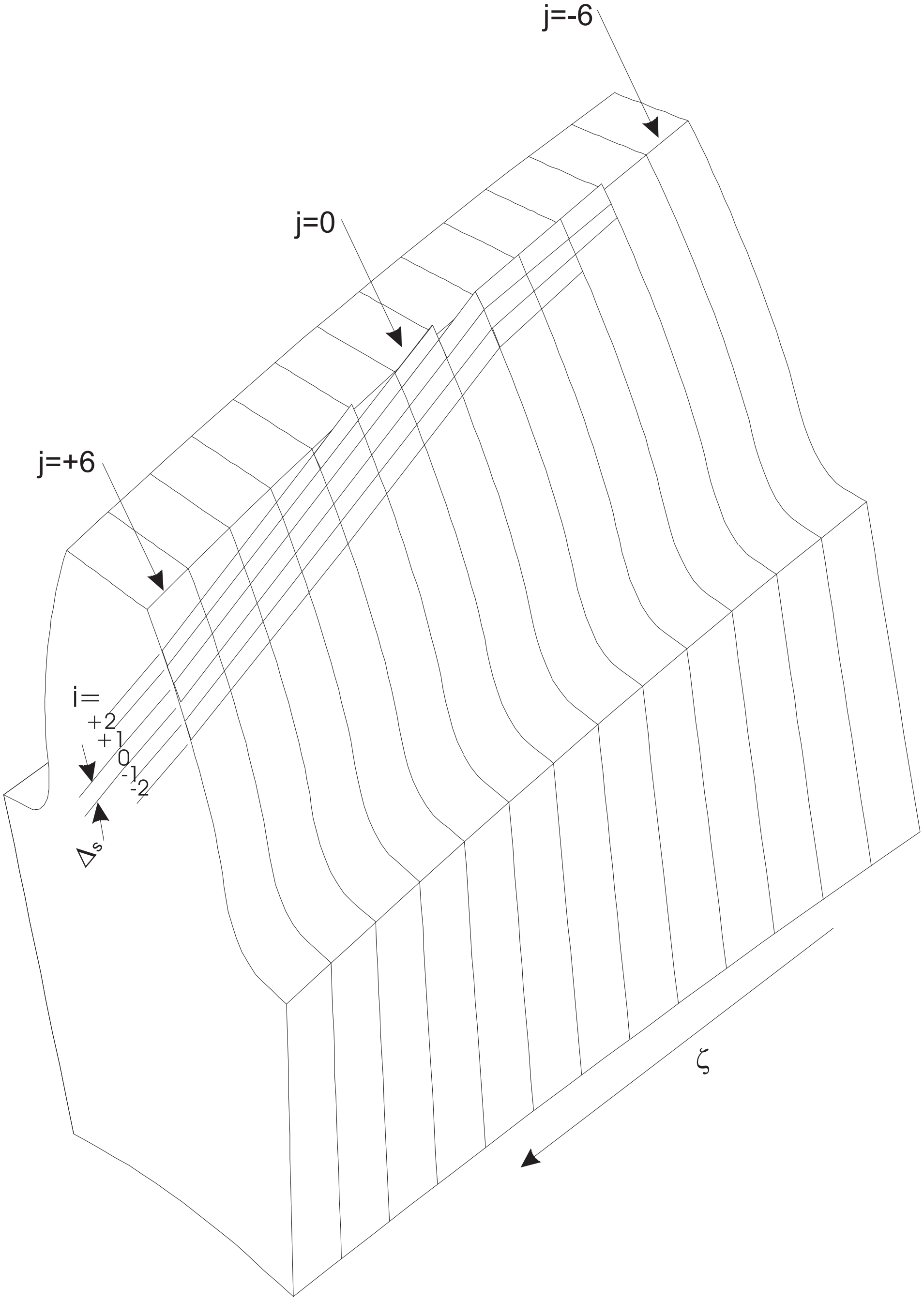

j=-6
j=0
j=+6
i=
+2
+1
0
-1
-2
Δs
ζ

Figure 9.4 Computational grid in the contact zone of the gears

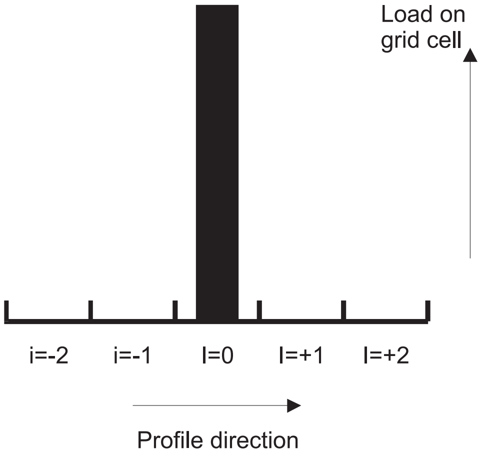


Figure 9.5 Contact pressure distribution across the width of contact obtained when the contact grid is too wide.

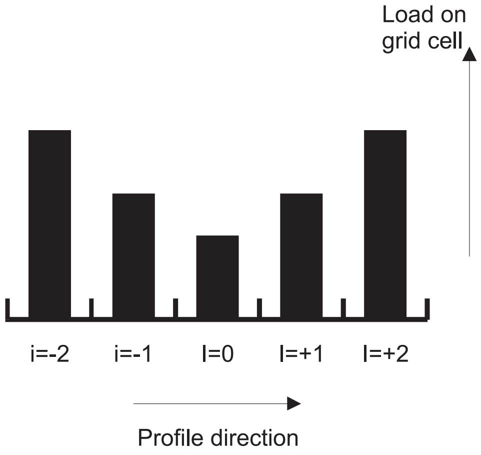


Figure 9.6 Contact pressure distribution across the width of contact obtained when the contact grid is too narrow.

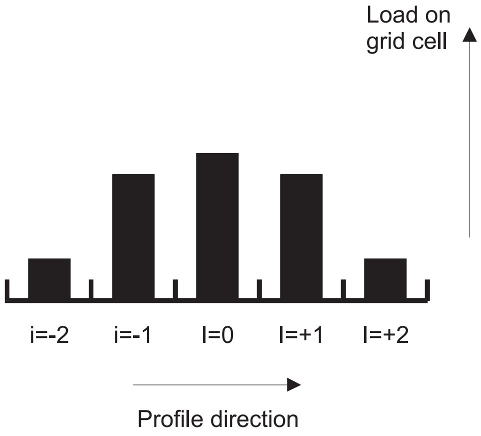


Figure 9.7 Contact pressure distribution across the width of contact obtained when the contact grid is correct.

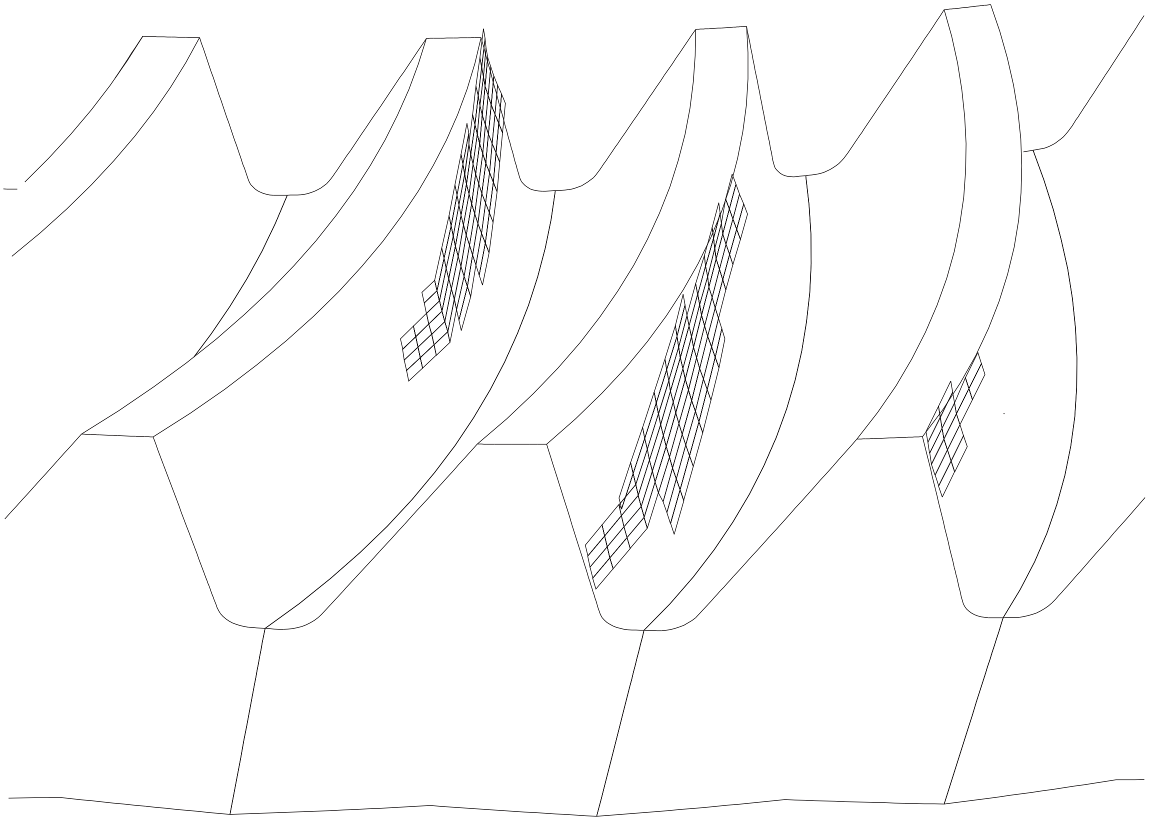


Figure 9.8 An example of a contact grid set up on a pair of contacting teeth.

9.5 The setup menu

Figure 9.9 shows the analysis setup menu accessed by using the SETUP command in the main menu. The parameters SEPTOL, NPROFDIVS, NFACEDIVS and DSPROF are the grid specification parameters described earlier. The initial state of the system can be specified as the undeformed state by enabling the ZEROINITIAL flag. The time at which to start the analysis is specified in the INITIALTIME box. If the ZEROINITIAL flag is not checked, then a restart file has to be specified, from which the deformed state and the value of time will be loaded. The analysis time is divided into a user-specified number NRANGES of time ranges. The time step DELTATIME, solution method SOLMETHOD and the number of time steps NTIMESTEPS can be specified separately for each time range.

For a *Transmission3D* system, we are usually only interested in running the model in static mode. So SOLMETHOD should be kept in this default state.

It is possible to control the operating speed in each time range by specifying a speed factor at the beginning of the range. A speed factor of 1.0 implies that the system is at its nominal speed. The speed factor at the end of a time range is the same as the speed factor at the beginning of the next time range. The speed at the end of the last range is always assumed 1.0. The speed is assumed to vary as a linear function of time within a time range.

The torque in a time range can be controlled by setting the STARTTORQUEFACTOR and ENDTORQUEFACTOR for each range. Again, a factor of 1.0 means that the system is operating at its nominal torque. The torque is assumed to vary as a linear function of time within a time range.

The SAVEPERIODICALLY option saves the state of the system in a restart file after every NSTEPSSAVE number of steps. The state is saved in the restart file named in the SAVEFILENAME box. This restart file can be used to restart another analysis. The OUTPUTRESTART option saves the state of the system in a restart file at the end of the analysis. The file named in the OUTPUTFILENAME box is used. This file can also be used to start a subsequent analysis.

Finally a finite element post-processing data file can be emitted once every NSTEPSWRITE number of time steps by enabling the POSTPROCWRITE option. The file used is selected in the POSTFILENAME box. The post-processing file can be used subsequently to make drawings and stress contour diagrams of the deformed system.

9.6 Other output files

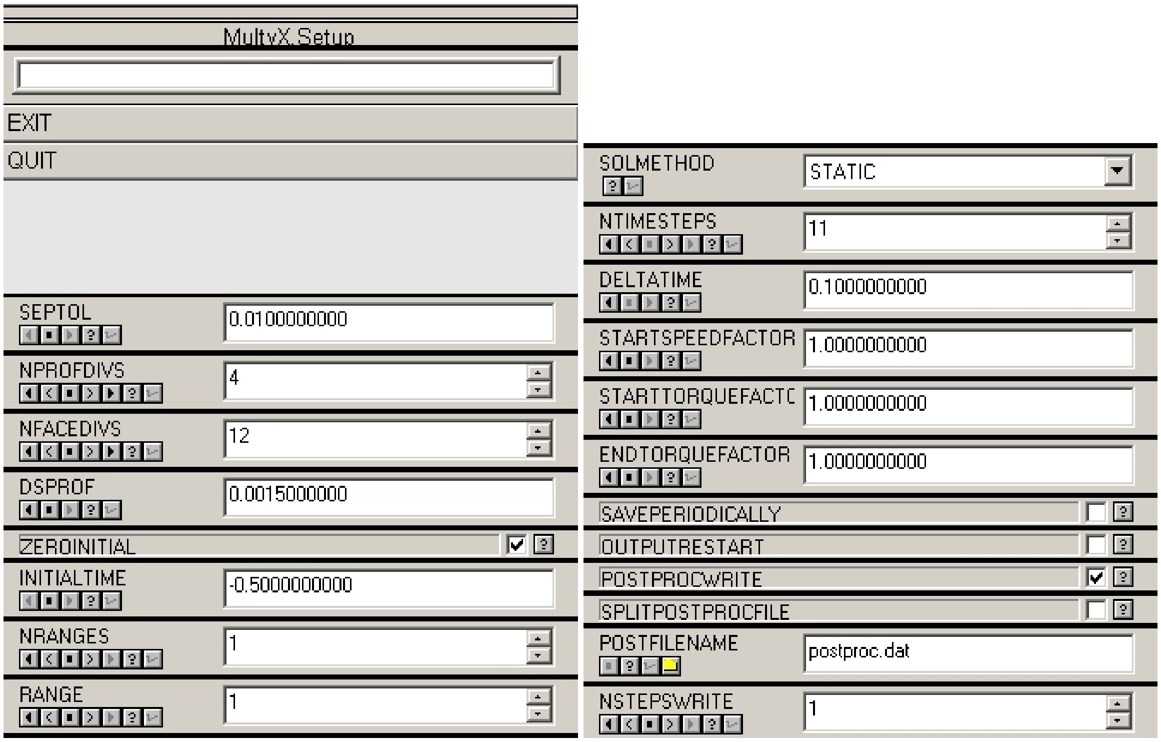
Several tabular output files are created during the analysis.

The displacements and reaction forces generated by the reference frames of the individual bodies in the system are saved in data files during analysis. These data files are named after the bodies. The file `RINGRES.DAT` contains the results for the ring gear, `SUNRES.DAT` contains results for the sun gear. Similarly `CARRIERRES.DAT` would have results for the carrier. Also, each pinion belonging to a group will have a separate data file. Each data file has one row for each instant of time analyzed. The first column contains the time. The next 6 columns contain the six components of reference frame deflection, u_x, u_y, u_z, θ_x, θ_y, and θ_z. The last 6 columns contain the 6 components of reference frame reaction, F_x, F_y, F_z, M_x, M_y, and M_z.

The deformation and reaction forces generated in each bearing are also saved in data files during analysis. The name of the result data file would be after the name of the bearing connection given in the connectors menu. Each data file has one row for each instant of time analyzed. The first column contains the time. The next 6 columns contain the six components of bearing deformation, u_x, u_y, u_z, θ_x, θ_y, and θ_z. The last 6 columns contain the 6 components of bearing reaction, F_x, F_y, F_z, M_y, M_y, and M_z.

The bearing deformation components are those of bearing race 1 with respect to race 2, measured in race 1.

The reaction forces are conjugates to the deformation values. So a positive deformation component causes a positive reaction force.

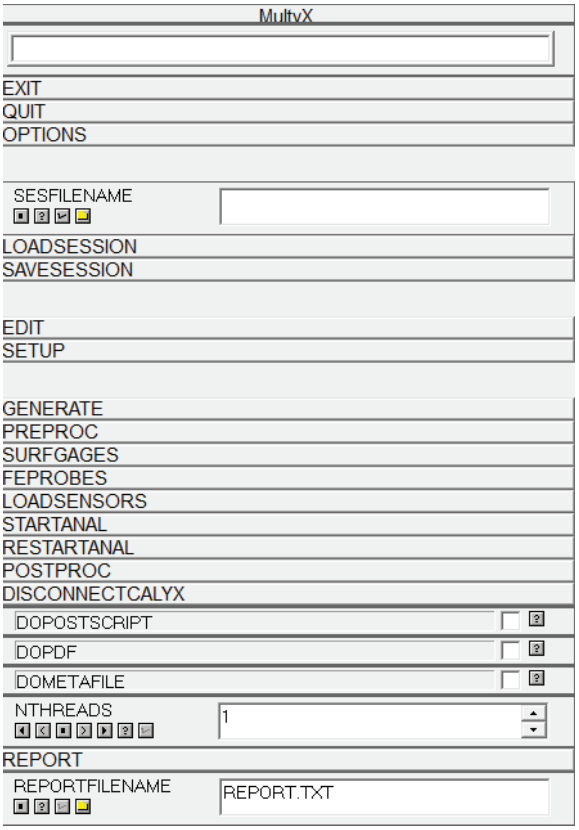


SEPTOL 0.0100000000
NPROFDIVS 4
NFACEDIVS 12
DSPROF 0.0015000000
ZEROINITIAL ☑
INITIALTIME -0.5000000000
NRANGES 1
RANGE 1
SOLMETHOD STATIC
NTIMESTEPS 11
DELTATIME 0.1000000000
STARTSPEEDFACTOR 1.0000000000
STARTTORQUEFACTC 1.0000000000
ENDTORQUEFACTOR 1.0000000000
SAVEPERIODICALLY ☐
OUTPUTRESTART ☐
POSTPROCWRITE ☑
SPLITPOSTPROCFILE ☐
POSTFILENAME postproc.dat
NSTEPSWRITE 1

Figure 9.9 The setup menu

9.7 Restarting an Analysis

In a case where an analysis is cancelled while running, the user can restart the analysis using the RESTARTANALYSIS command in the main menu shown in Figure 9.10. This command can be used to restart an analysis providing the session file remains unchanged from the original session. The setup parameters, including the number of time steps and delta time parameters must also remain the same. This feature cannot be used to extend an analysis by a certain number of time steps. To restart the analysis, simply load the session file located within the same working folder as the original analysis files (calyxtmp folder and postproc.dat folder/file) and select the RESTARTANALYSIS button.


MultyX
EXIT
QUIT
OPTIONS
SESFILENAME
LOADSESSION
SAVESESSION
EDIT
SETUP
GENERATE
PREPROC
SURFGAGES
FEPROBES
LOADSENSORS
STARTANAL
RESTARTANAL
POSTPROC
DISCONNECTCALYX
DOPOSTSCRIPT ☐
DOPDF ☐
DOMETAFILE ☐
REPORT

NTHREADS 1

REPORTFILENAME REPORT.TXT

Figure 9.10 The main menu showing the RESTARTANALYSIS command.

CHAPTER 10

PRE- AND POST-PROCESSING

The PREPROC command in the main menu leads to the pre-processing menu shown in Figure 10.1. The POSTPROC command leads to the dialog box shown in Figure 10.2, where *Multyx* asks for the name of the post-processing data file created in the analysis step. When a valid name is entered, the post-processing menu shown in Figure 10.3 comes up.

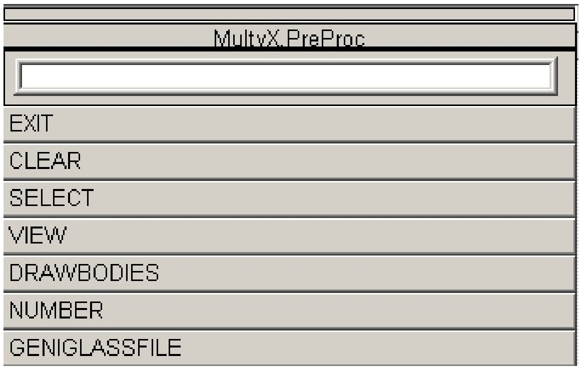


Figure 10.1 The pre-processing menu.

The pre-processing menu and the post-processing menu are used to make drawings of the system and its components. The CLEAR command clears the graphics screen. The DRAWBODIES draws all the selected bodies using the current view settings. The DRAWBODIES command does not clear the screen before it makes the drawing. In the post-processing menu, the FIRSTPOSN, PREVPOSN, NEXTPOSN, and LASTPOSN commands allow the user to move from one time step saved in the post-processing file to another. Entering a position number directly in the GOTOPOSN box takes the user directly to that time step.

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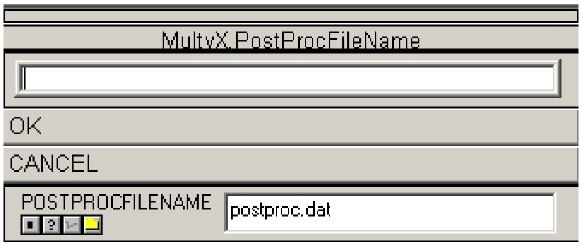
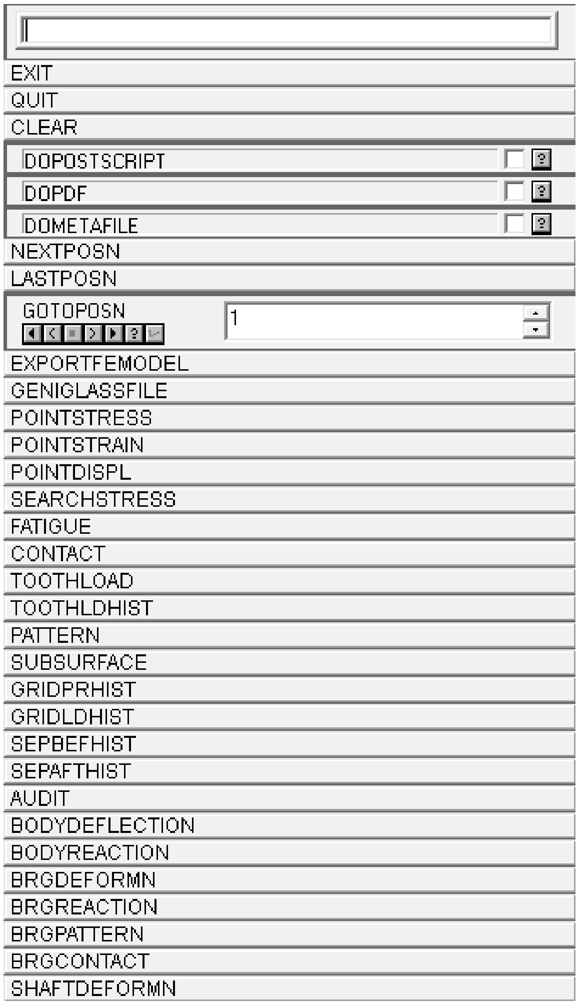

MultyX.PostProcFileName
OK
CANCEL

POSTPROCFILENAME postproc.dat

Figure 10.2 The post-processing file name dialog box.

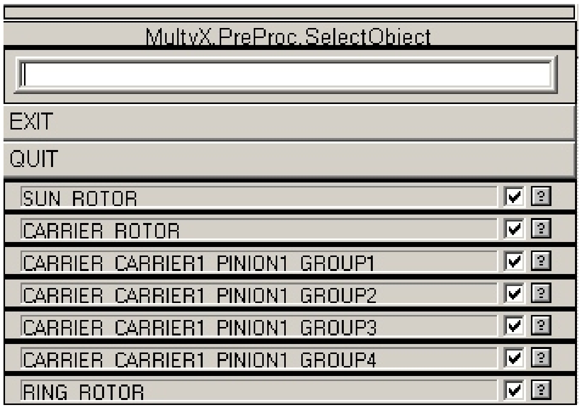

EXIT
QUIT
CLEAR
DOPOSTSCRIPT
DOPDF
DOMETAFILE
NEXTPOSN
LASTPOSN
EXPORTFEMODEL
GENIGLASSFILE
POINTSTRESS
POINTSTRAIN
POINTDISPL
SEARCHSTRESS
FATIGUE
CONTACT
TOOTHLOAD
TOOTHLDHIST
PATTERN
SUBSURFACE
GRIDPRHIST
GRIDLDHIST
SEPBEFHIST
SEPAFTHIST
AUDIT
BODYDEFLECTION
BODYREACTION
BRGDEFORMN
BRGREACTION
BRGPATTERN
BRGCONTACT
SHAFTDEFORMN

DOPOSTSCRIPT ☐
DOPDF ☐
DOMETAFILE ☐
GOTOPOSN 1

Figure 10.3 The post-processing menu.

10.1 Selecting bodies

The object selection menu which appears when the SELECT command is invoked from the pre- and post-processing menus is shown in Figure 10.4. The objects that should be drawn are selected from this menu.



SUN ROTOR ☑
CARRIER ROTOR ☑
CARRIER CARRIER1 PINION1 GROUP1 ☑
CARRIER CARRIER1 PINION1 GROUP2 ☑
CARRIER CARRIER1 PINION1 GROUP3 ☑
CARRIER CARRIER1 PINION1 GROUP4 ☑
RING ROTOR ☑

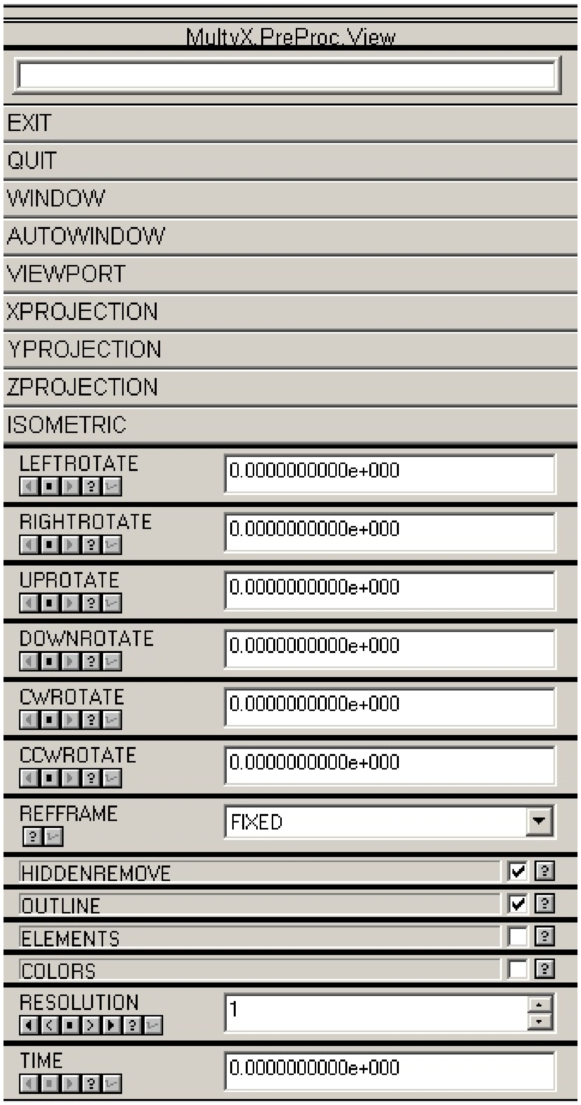
Figure 10.4 The body selection menu.

10.2 View parameters

The VIEW menu controls the appearance of the drawings. In the pre-processing view menu shown in Figure 10.5, the user can enter any value of time into the TIME box. The next drawing will show the system as it would appear at this instant of time. The resolution level controls the degree of detail with which the drawing is made. The ELEMENTS checkbox controls whether or not the individual finite elements should be drawn. The COLORS option controls whether or not the bodies will be filled with color. In pre-processing mode, all bodies are painted Gray. The OUTLINE box controls whether or not an outline drawing of the body will be made.

The view menu in post-processing mode (Figure 10.6) has a few additional parameters. There is a CONTOURS option to draw stress contours. If the COLORS or CONTOURS option is selected, then the menu also asks for the values of the lowest contour level MINSTRESS and the highest contour level MAXSTRESS. The colors used in the drawing are based on the stress level. If the LOADS option is selected, then the contact loads acting on the components will be drawn using the scale factor entered in the LOADSCALE box.

If the LOADS option is not checked (Figure 10.7), then an additional box EXAGGERATION appears where an exaggeration factor can by entered for deformed geometry plots. An exaggeration factor of 0.0 will draw the bodies in their undeformed state.


MultyX.PreProc.View
EXIT
QUIT
WINDOW
AUTOWINDOW
VIEWPORT
XPROJECTION
YPROJECTION
ZPROJECTION
ISOMETRIC

LEFTROTATE 0.0000000000e+000

RIGHTROTATE 0.0000000000e+000

UPROTATE 0.0000000000e+000

DOWNROTATE 0.0000000000e+000

CWROTATE 0.0000000000e+000

CCWROTATE 0.0000000000e+000

REFFRAME FIXED

HIDDENREMOVE ☑

OUTLINE ☑

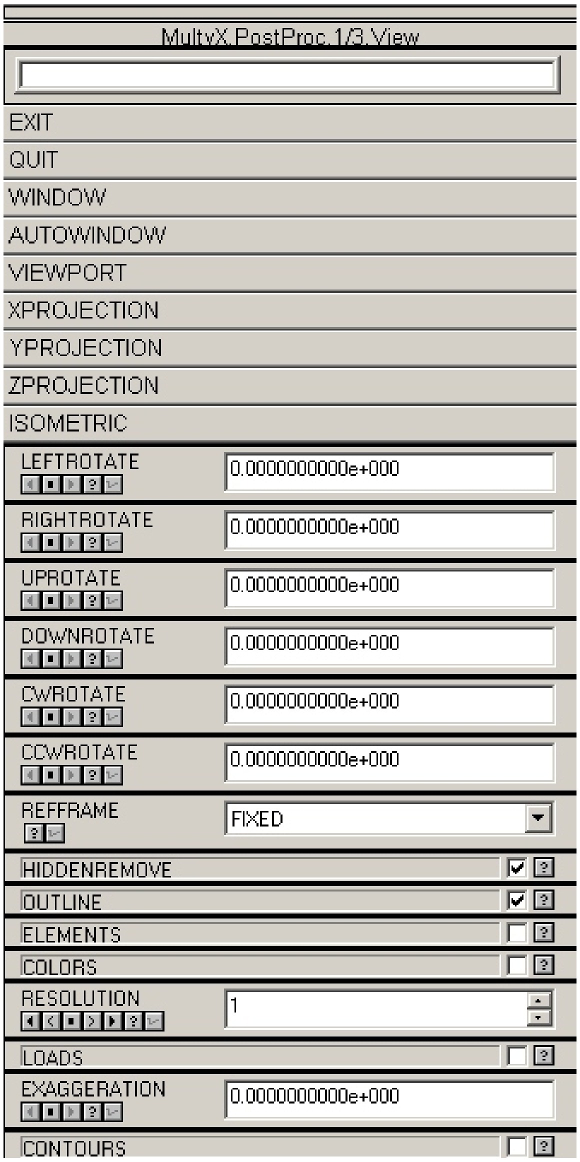
ELEMENTS ☐

COLORS ☐

RESOLUTION 1

TIME 0.0000000000e+000

Figure 10.5 The view menu in pre-processing mode.


MultyX.PostProc.1/3.View
EXIT
QUIT
WINDOW
AUTOWINDOW
VIEWPORT
XPROJECTION
YPROJECTION
ZPROJECTION
ISOMETRIC

LEFTROTATE 0.0000000000e+000

RIGHTROTATE 0.0000000000e+000

UPROTATE 0.0000000000e+000

DOWNROTATE 0.0000000000e+000

CWROTATE 0.0000000000e+000

CCWROTATE 0.0000000000e+000

REFFRAME FIXED

HIDDENREMOVE ☑

OUTLINE ☑

ELEMENTS ☐

COLORS ☐

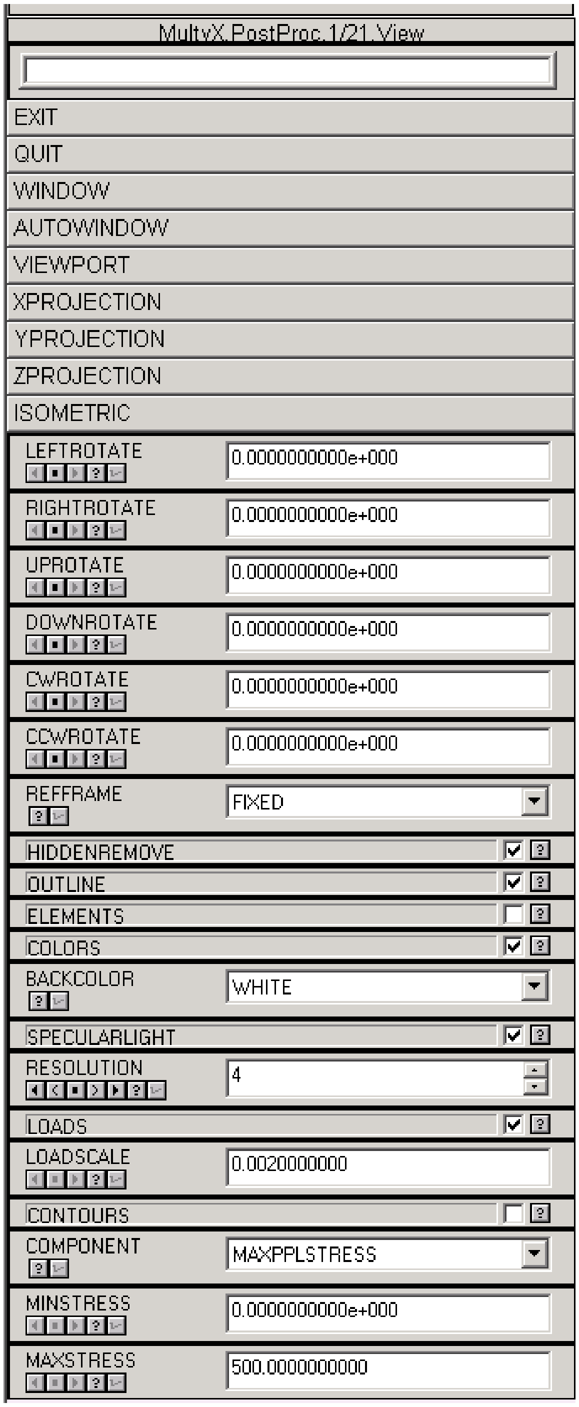
RESOLUTION 1

LOADS ☐

EXAGGERATION 0.0000000000e+000

CONTOURS ☐

Figure 10.6 The view menu in post-processing mode with the LOADS option disabled.


MultyX.PostProc.1/21.View
EXIT
QUIT
WINDOW
AUTOWINDOW
VIEWPORT
XPROJECTION
YPROJECTION
ZPROJECTION
ISOMETRIC

LEFTROTATE 0.0000000000e+000

RIGHTROTATE 0.0000000000e+000

UPROTATE 0.0000000000e+000

DOWNROTATE 0.0000000000e+000

CWROTATE 0.0000000000e+000

CCWROTATE 0.0000000000e+000

REFFRAME FIXED

HIDDENREMOVE ☑

OUTLINE ☑

ELEMENTS ☐

COLORS ☑

BACKCOLOR WHITE

SPECULARLIGHT ☑

RESOLUTION 4

LOADS ☑

LOADSCALE 0.0020000000

CONTOURS ☐

COMPONENT MAXPPLSTRESS

MINSTRESS 0.0000000000e+000

MAXSTRESS 500.0000000000

Figure 10.7 The view menu in post-processing mode with the LOADS option enabled.

10.3 The DRAWBODIES command

After an appropriate view and objects have been selected, the DRAWBODIES command in the pre- and post-processing menus (Figures 10.1 and 10.3) will generate a drawing. Figures 10.8 and 10.9 show examples of drawings generated by *Multyx* in the post-processing mode.

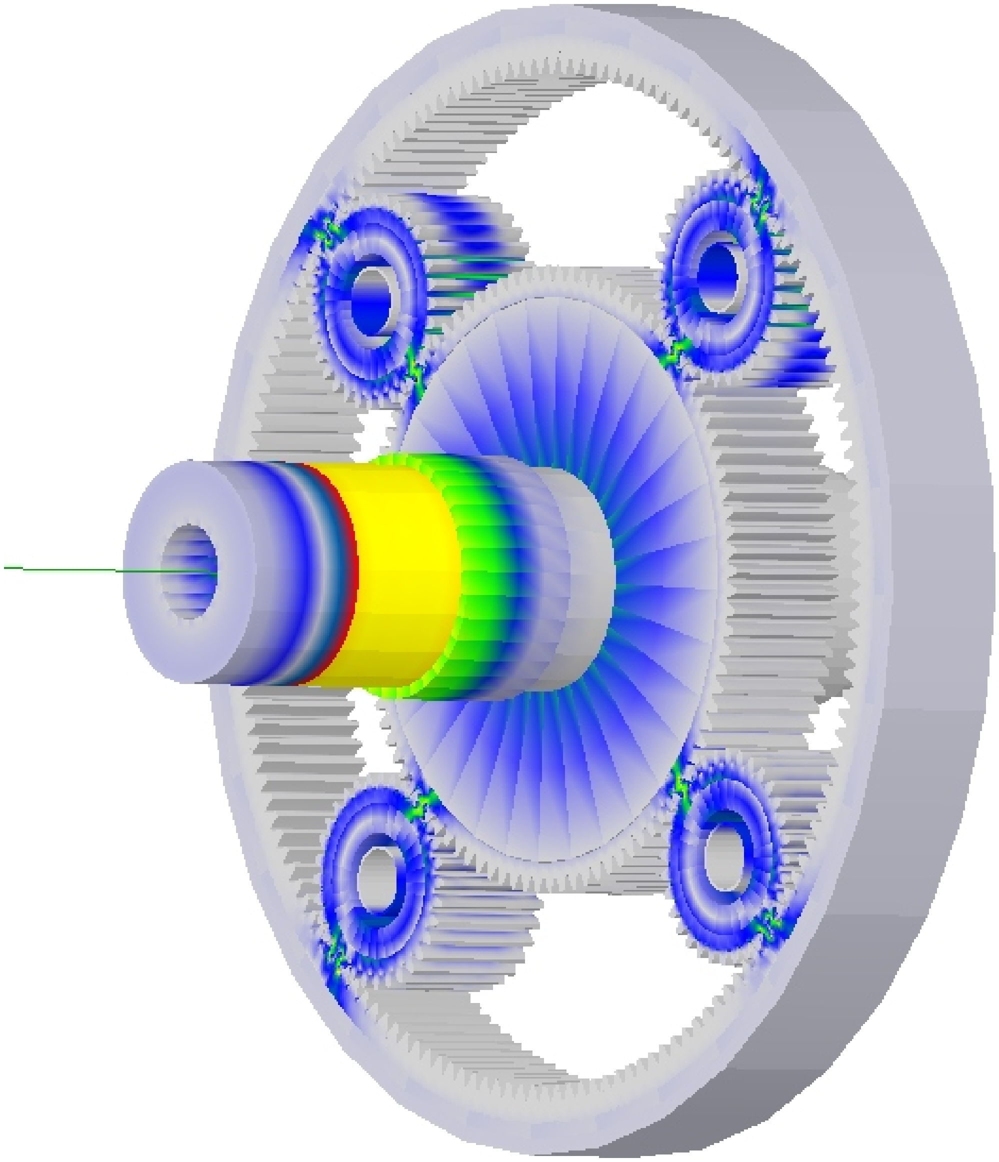


Figure 10.8 An example of a drawing made in post-processing mode.

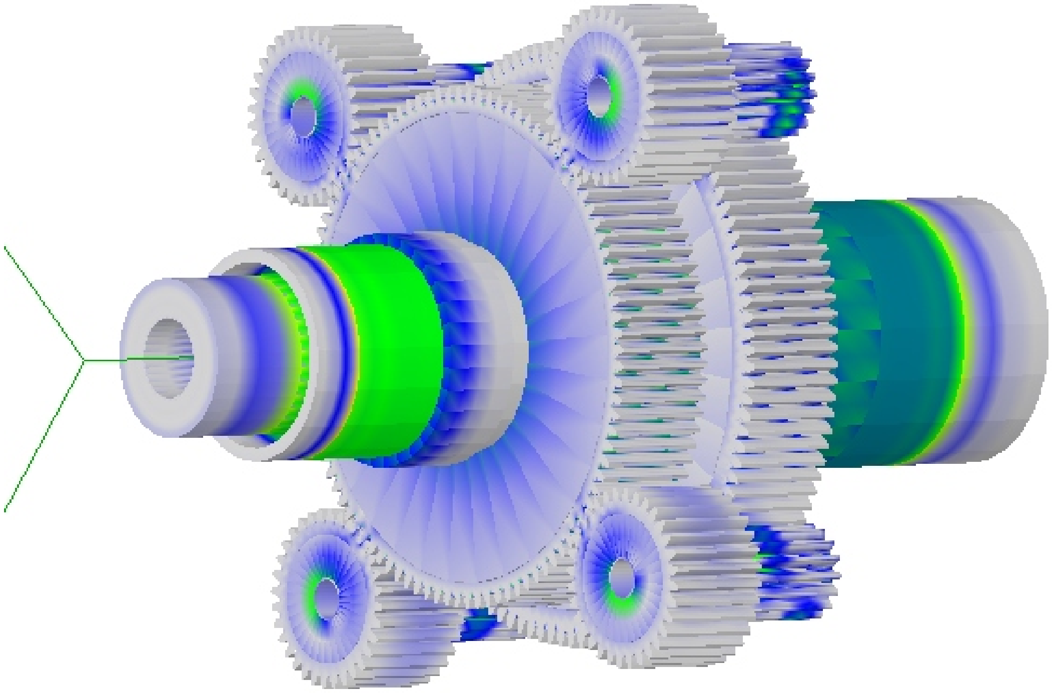
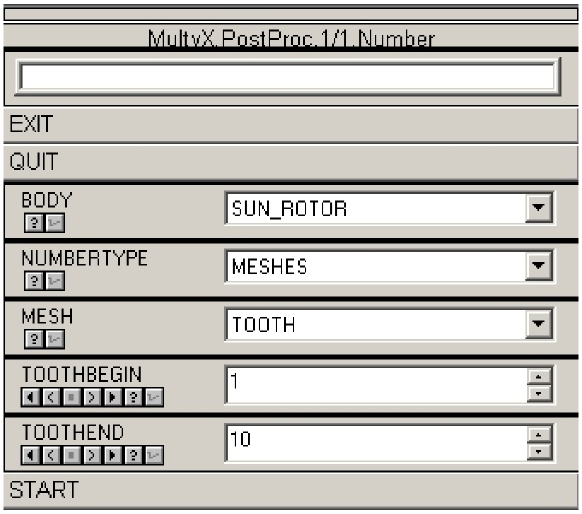


Figure 10.9 An example of a drawing made in post-processing mode.

10.4 The NUMBER command

The NUMBER command in the pre- and post-processing menus (Figures 10.1 and 10.3) lead to the numbering menu shown in Figure 10.10. This menu is used to to generate tooth and surface numbering, as shown in Figure 10.11.


MultyX.PostProc.1/1.Number
EXIT
QUIT
START

BODY SUN_ROTOR
NUMBERTYPE MESHES
MESH TOOTH
TOOTHBEGIN 1
TOOTHEND 10

Figure 10.10 The NUMBER menu.

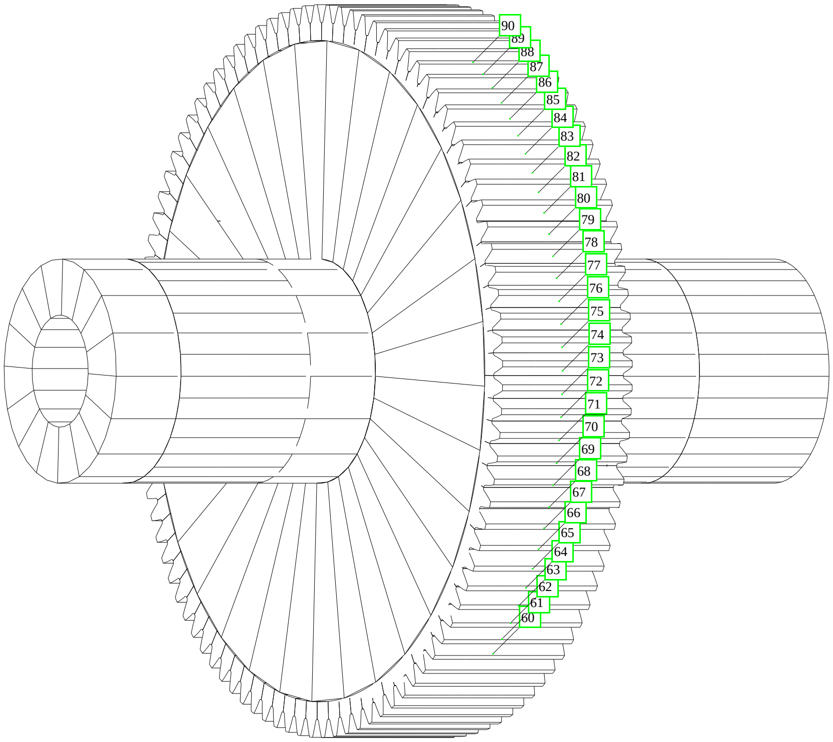
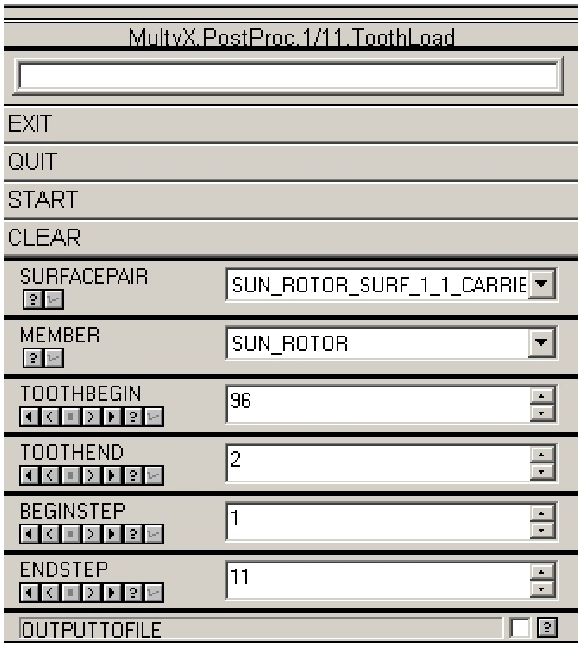

90
89
88
87
86
85
84
83
82
81
80
79
78
77
76
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60

Figure 10.11 Tooth numbering superimposed on a pinion drawing, using the NUMBER command.



SURFACEPAIR SUN_ROTOR_SURF_1_1_CARRIE

MEMBER SUN_ROTOR

TOOTHBEGIN 96

TOOTHEND 2

BEGINSTEP 1

ENDSTEP 11

OUTPUTTOFILE ☐

Figure 10.12 The TOOTHLOAD menu.

10.5 The TOOTHLOAD command

The TOOTHLOAD command in the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.12. This menu is used to generate a graph of tooth load vs. time. The SURFACEPAIR item selects the contact surface pair for which the load is of interest. Each surface pair has two contacting members or bodies. The MEMBER parameter selects one of these two bodies, and the TOOTHBEGIN and TOOTHEND items select a range of instance numbers (or tooth numbers) within that body. If TOOTHBEGIN is greater than TOOTHEND, then the range wraps around the last tooth of the surface. This range must contain 7 teeth or less.

BEGINSTEP and ENDSTEP are used to select a range of time steps for which results have been stored in the post-processing file. Figure 10.13 shows a graph of tooth load vs. time generated by the TOOTHLOAD command.

The OUTPUTFILENAME item is used to write the tooth load data into an ASCII file. The name of the ASCII file is entered into the item OUTPUTFILENAME. If the APPEND box is checked, and if this file already exists, then the data is appended at the end of the file. Otherwise a new file is created.

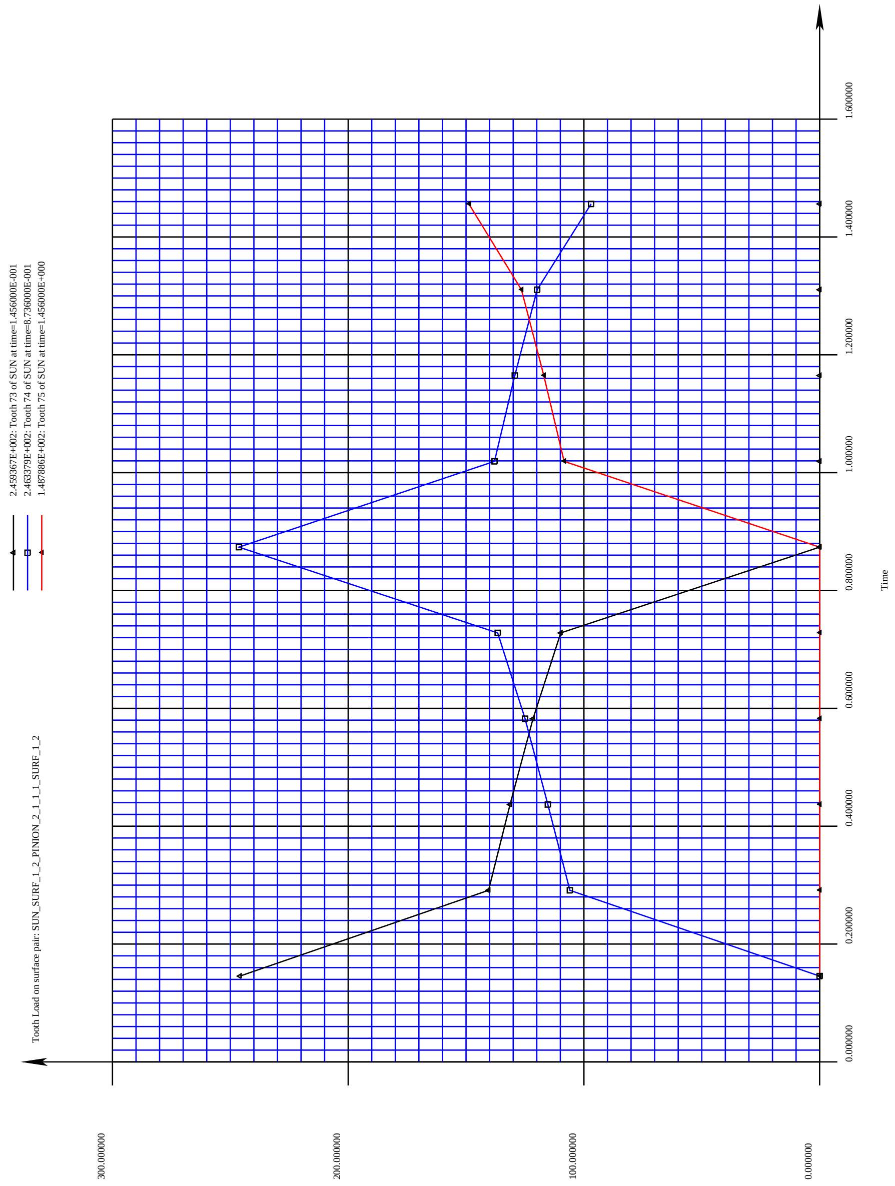
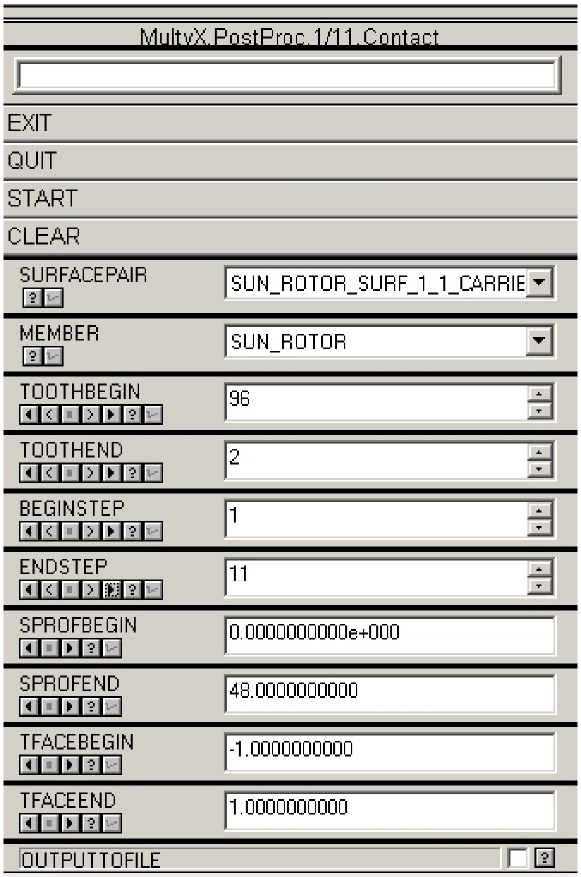


Figure 10.13 The tooth load vs. time graph generated by the TOOTHLOAD menu.



MultyX.PostProc.1/11.Contact

SURFACEPAIR	SUN_ROTOR_SURF_1_1_CARRIE
MEMBER	SUN_ROTOR
TOOTHBEGIN	96
TOOTHEND	2
BEGINSTEP	1
ENDSTEP	11
SPROFBEGIN	0.0000000000e+000
SPROFEND	48.0000000000
TFACEBEGIN	-1.0000000000
TFACEEND	1.0000000000
OUTPUTTOFILE	☐

Figure 10.14 The CONTACT menu.

10.6 The CONTACT command

The CONTACT command in the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.14. This menu is used to generate a graph of contact pressure vs. time.

The SURFACEPAIR item selects the contact surface pair for which the pressure is of interest. Each surface pair has two contacting members or bodies. The MEMBER parameter selects one of these two bodies, and the TOOTHBEGIN and TOOTHEND items select a range of instance numbers (or tooth numbers) within that body. If TOOTHBEGIN is greater than TOOTHEND, then the range wraps around the last tooth of the surface. This range must contain 7 teeth or less. The items SPROFBEGIN, SPROFEND, TFACEBEGIN and TFACEEND are used to restrict the search to a part of the contact surface. Contact occurring outside this range is not considered for display in this graph.

Figure 10.15 shows a graph of contact pressure vs. time over the entire surface of a pinion tooth. Very high contact pressures are observed near the tips of the pinion and gear teeth. This high contact pressure near the edges can be filtered out by restricting the search range, as shown in Figure 10.16.

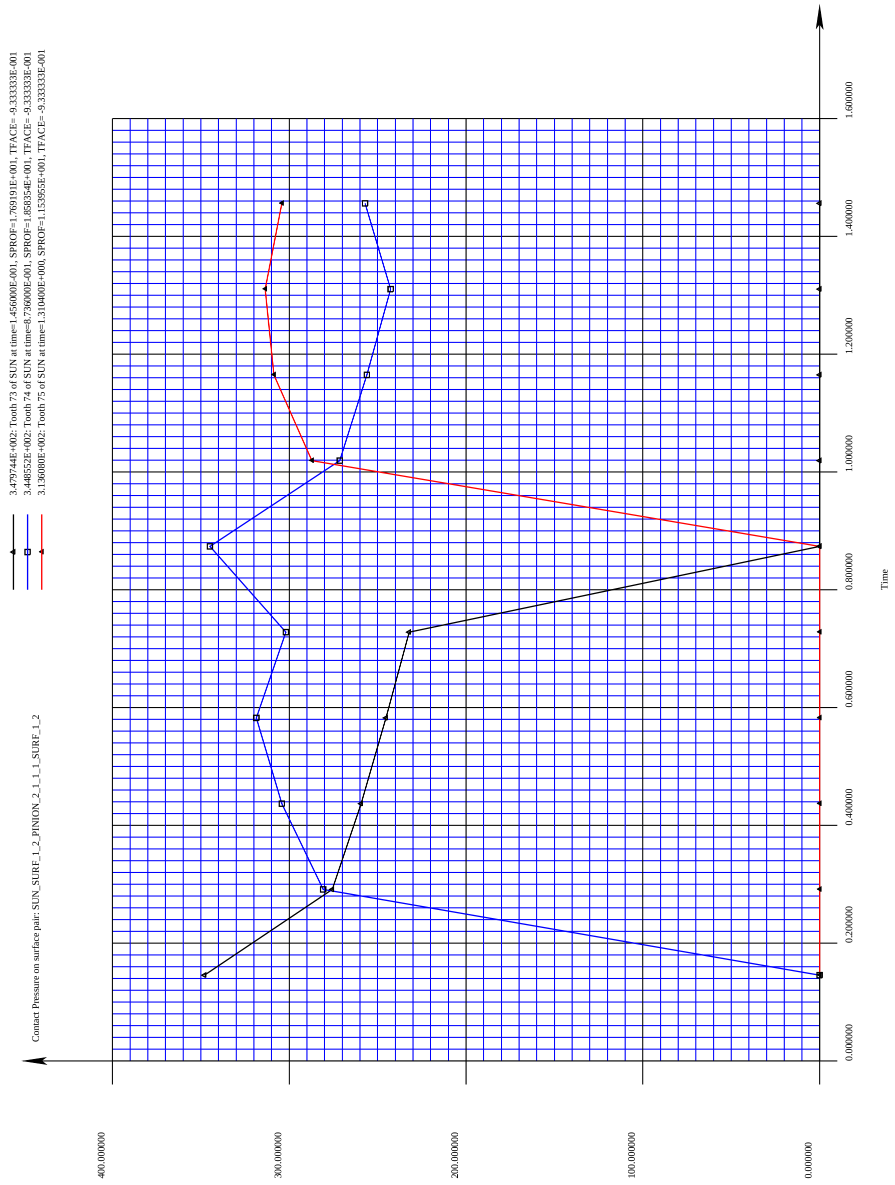


Figure 10.15 The tooth contact pressure vs. time graph generated by the CONTACT menu.

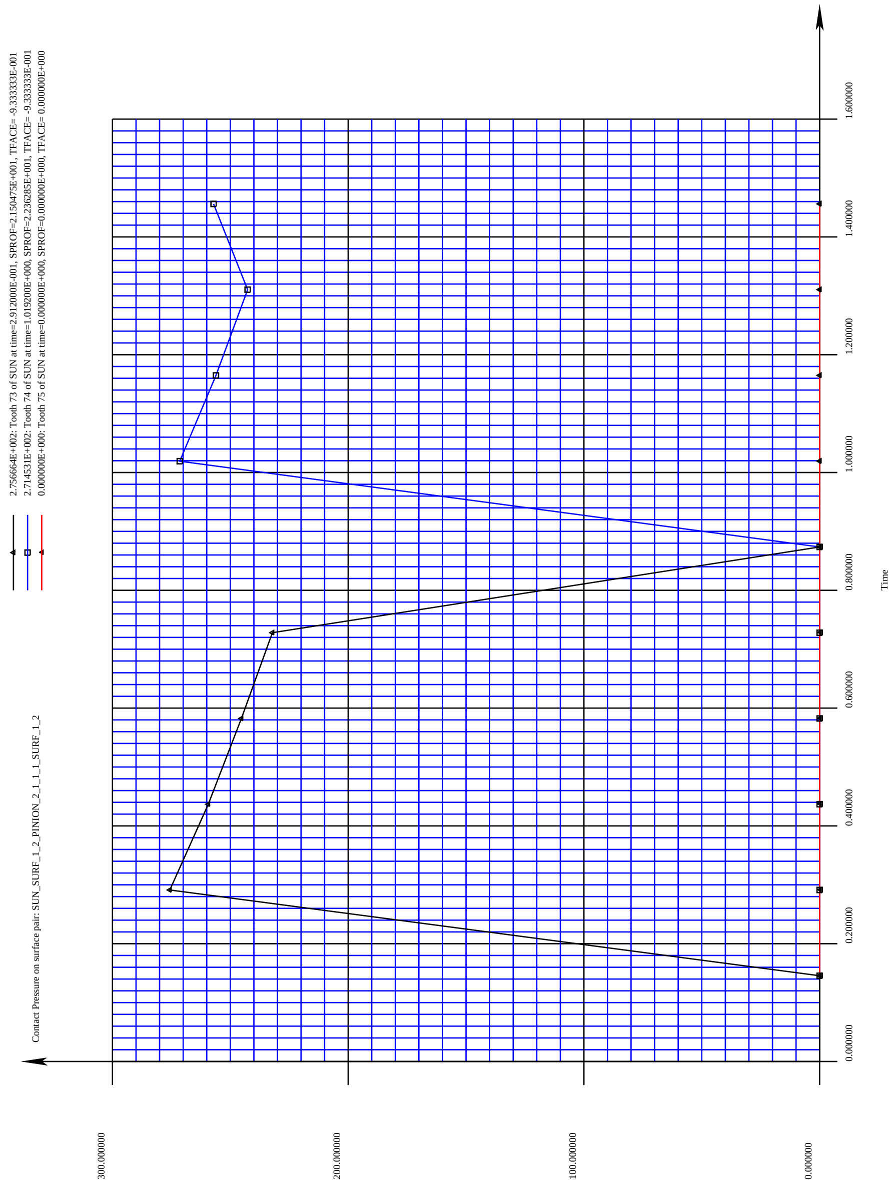
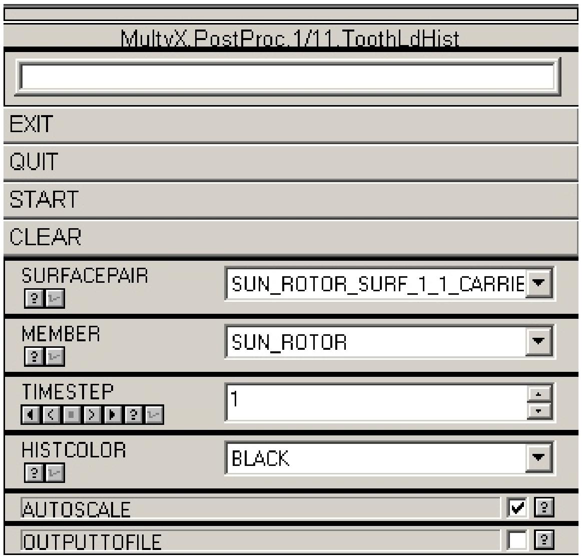


Figure 10.16 The tooth contact pressure vs. time graph generated by the CONTACT menu with the search range limited to $20 \leq s_{prof} \leq 48$.



SURFACEPAIR SUN_ROTOR_SURF_1_1_CARRIE

MEMBER SUN_ROTOR

TIMESTEP 1

HISTCOLOR BLACK

AUTOSCALE ☑

OUTPUTTOFILE ☐

Figure 10.17 The TOOTHLDHIST menu.

10.7 The TOOTHLDHIST command

The TOOTHLDHIST command in the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.17. This menu is used to generate a histogram of tooth loads at the different teeth in the pinion or gear at a particular time step. The SURFACEPAIR item selects the surface pair, and the MEMBER parameter selects one of the two bodies in this pair. The time step number is selected by the TIMESTEP item. If the AUTOSCALE box is checked, then the vertical scale is automatically computed. Otherwise the user can specify a maximum load value to be used for scaling the vertical axis. The color of the histogram is specified in the HISTCOLOR item. An example of a tooth load histogram is shown in Figure 10.18.

10.8 The SUBSURFACE command

The SUBSURFACE command in the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.19. This menu is used to generate a graph of subsurface stresses vs. depth under the most critical point in the contact zone. The items TOOTHBEGIN and TOOTHEND are used to select a range of surface instances (tooth numbers). There can be at most 7 teeth in this range.

The items DEPTHBEGIN and DEPTHEND define a depth range, and NUMDEPTH specifies the number of points over this range. Very close to the surface, the subsurface stresses have a large error because of the concentrated nature of the load. So DEPTHBEGIN should never be set to zero.

The stress component is selected in the COMPONENT box. Options available are MAXPPLNORMAL (the maximum principal normal stress s_1), MINPPLNORMAL (the minimum principal normal stress s_3), MAXSHEAR (the maximum shear stress τ_{max}) and VONMISES (the Von Mises' octahedral shear stress s_{VM}).

Figure 10.20 shows an example of a graph of sub-surface stress vs. depth.

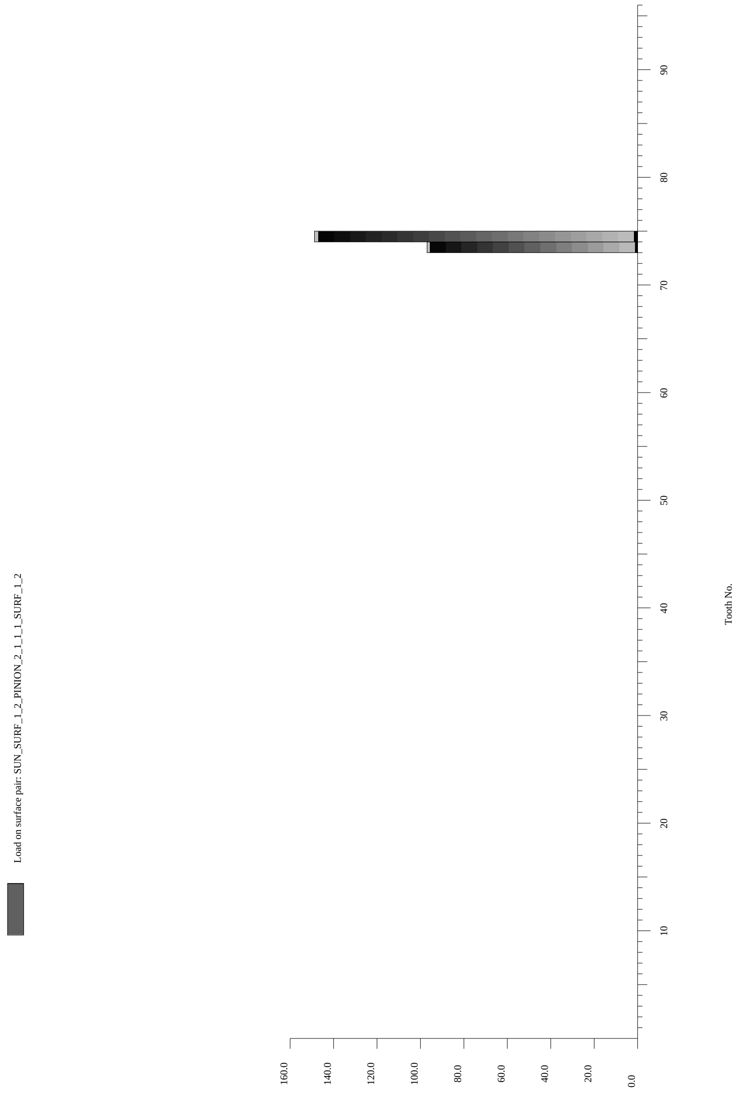
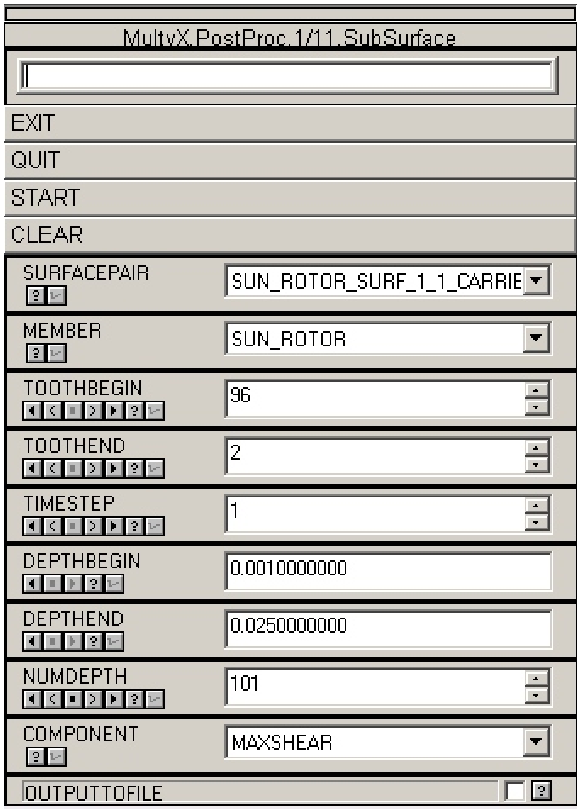


Figure 10.18 The tooth load histogram generated by the TOOTHLDHIST menu.


MultyX.PostProc.1/11.SubSurface
EXIT
QUIT
START
CLEAR

SURFACEPAIR SUN_ROTOR_SURF_1_1_CARRIE
MEMBER SUN_ROTOR
TOOTHBEGIN 96
TOOTHEND 2
TIMESTEP 1
DEPTHBEGIN 0.0010000000
DEPTHEND 0.0250000000
NUMDEPTH 101
COMPONENT MAXSHEAR
OUTPUTTOFILE ☐

Figure 10.19 The SUBSURFACE menu.

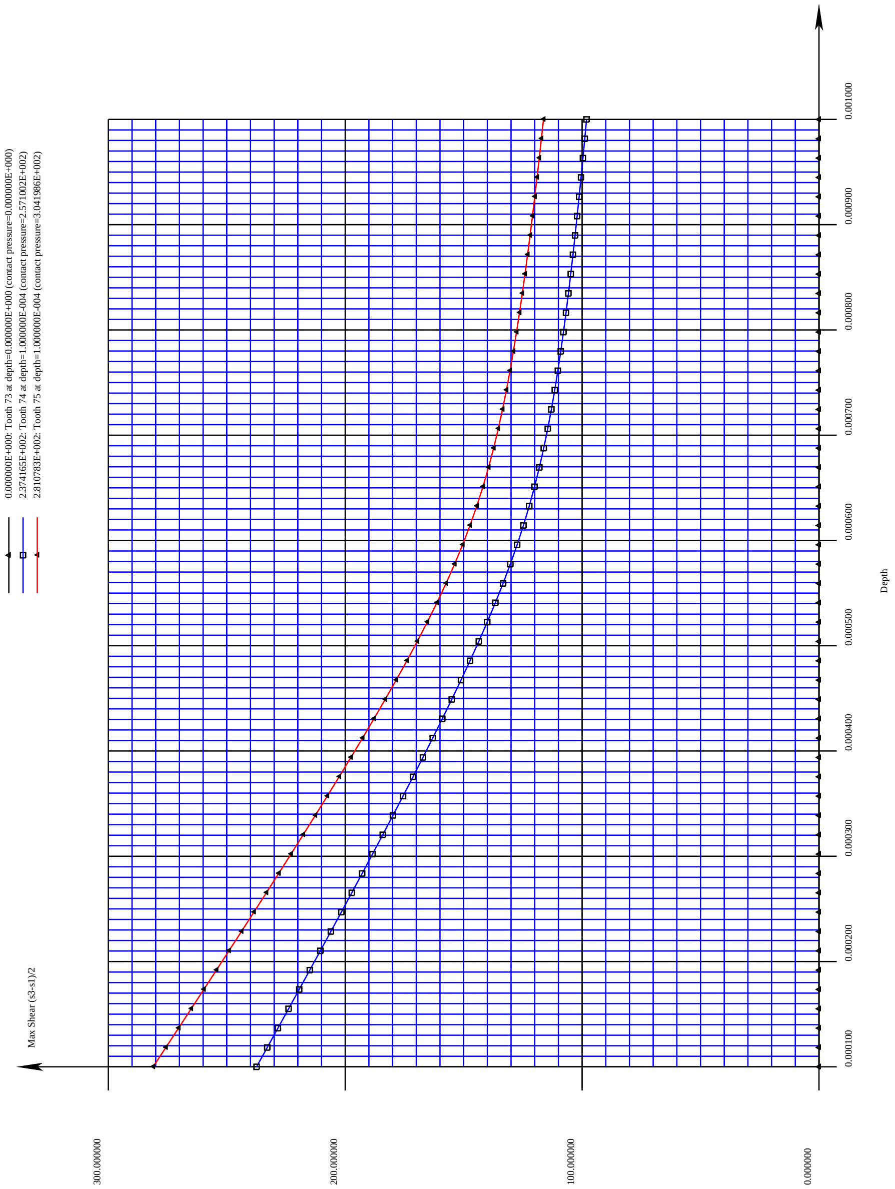
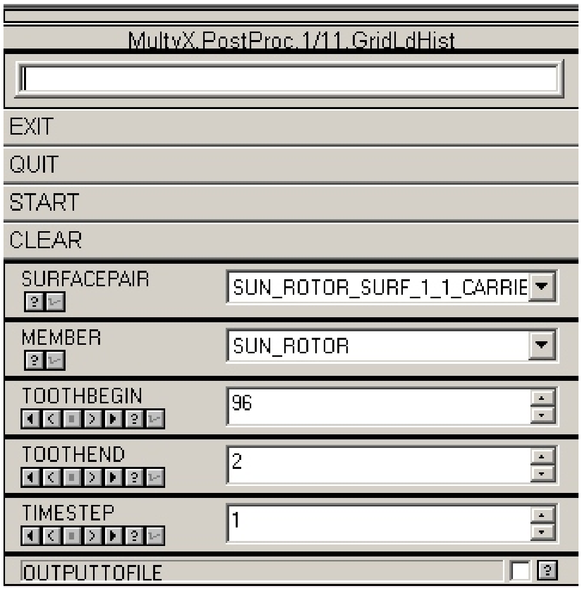


Figure 10.20 The sub-surface shear graph generated by the SUBSURFACE menu.



SURFACEPAIR SUN_ROTOR_SURF_1_1_CARRIE
MEMBER SUN_ROTOR
TOOTHBEGIN 96
TOOTHEND 2
TIMESTEP 1
OUTPUTTOFILE ☐

Figure 10.21 The GRIDLDHIST menu.

10.9 The GRIDLDHIST command

The GRIDLDHIST command in the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.21. This menu is used to generate a histogram of the distribution of contact load over individual contact grid cells. This figure is useful in determining whether the contact grid cell has been properly sized, and whether it has adequate resolution.

The SURFACEPAIR item selects the surface pair, and the MEMBER parameter selects one of the two bodies in this pair. The items TOOTHBEGIN and TOOTHEND are used to select a range of surface instances (tooth numbers). There can be at most 7 teeth in this range. The item TIMESTEP selects a time step number.

Figure 10.22 shows an example of a grid load histogram.

10.10 The GRIDPRHIST command

The GRIDPRHIST command in the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.23. This menu is used to generate a histogram of the distribution of contact pressure over individual contact grid cells. This command is very similar to the GRIDLDHIST command. The only difference is that it uses contact pressure instead of contact load.

Figure 10.24 shows an example of a grid pressure histogram.

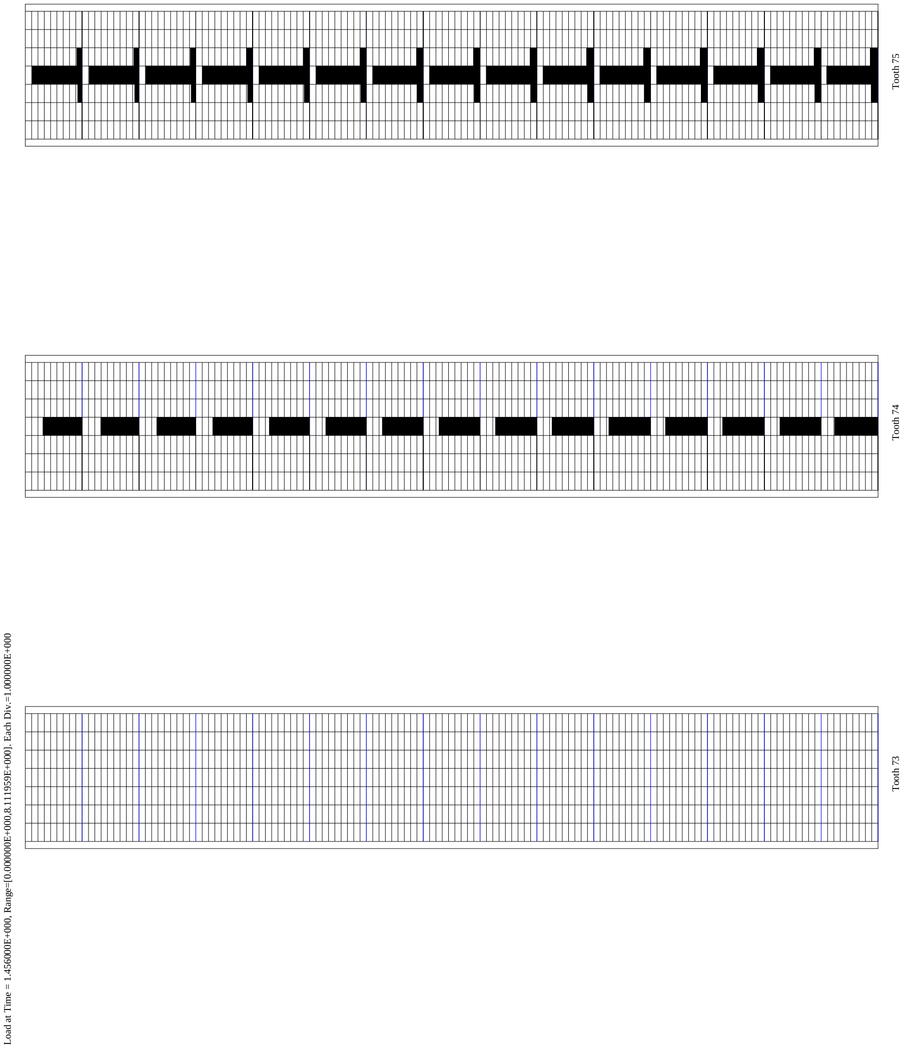
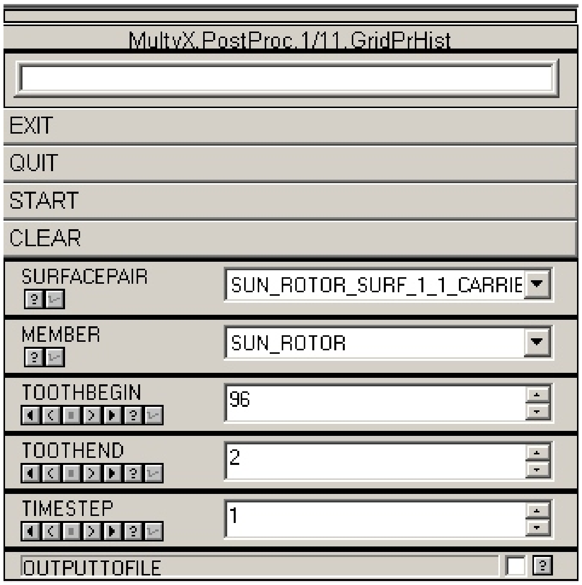


Figure 10.22 The grid load histogram generated by the GRIDLDHIST menu.


MultyX.PostProc.1/11.GridPrHist
EXIT
QUIT
START
CLEAR

SURFACEPAIR: SUN_ROTOR_SURF_1_1_CARRIE

MEMBER: SUN_ROTOR

TOOTHBEGIN: 96

TOOTHEND: 2

TIMESTEP: 1

OUTPUTTOFILE ☐

Figure 10.23 The GRIDPRHIST menu.

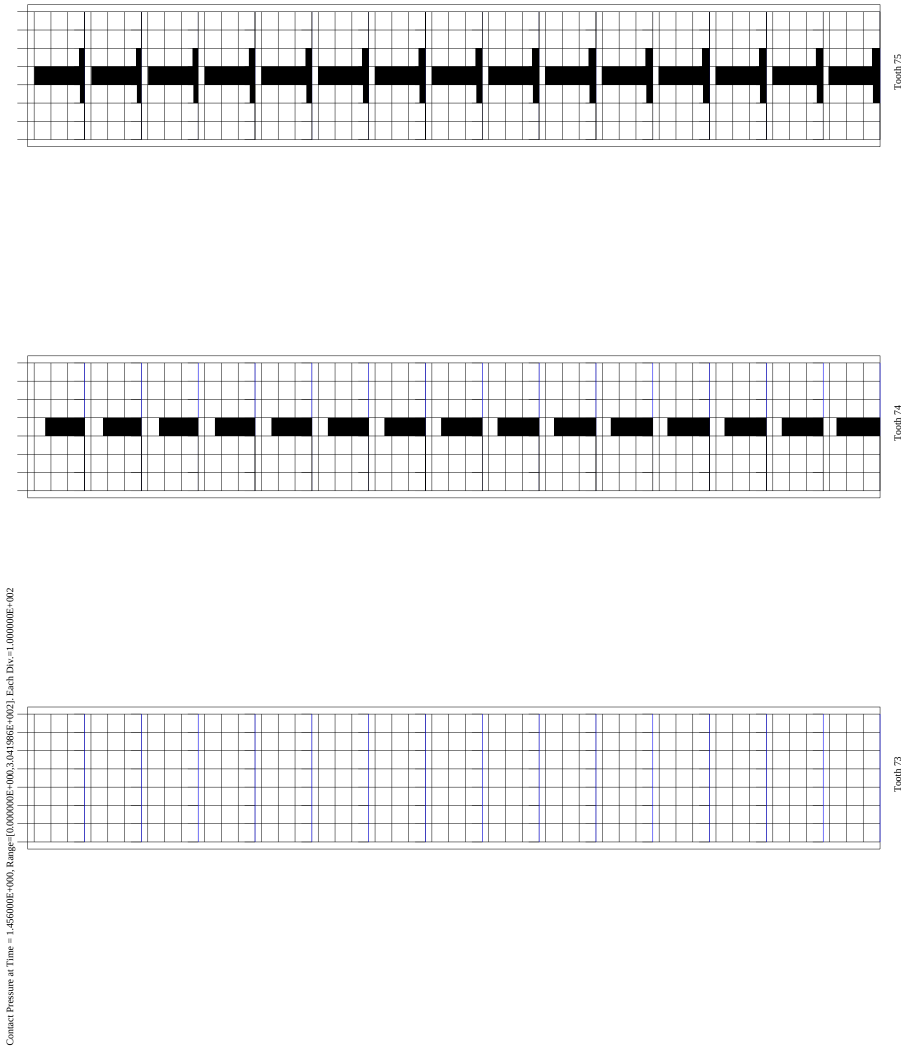
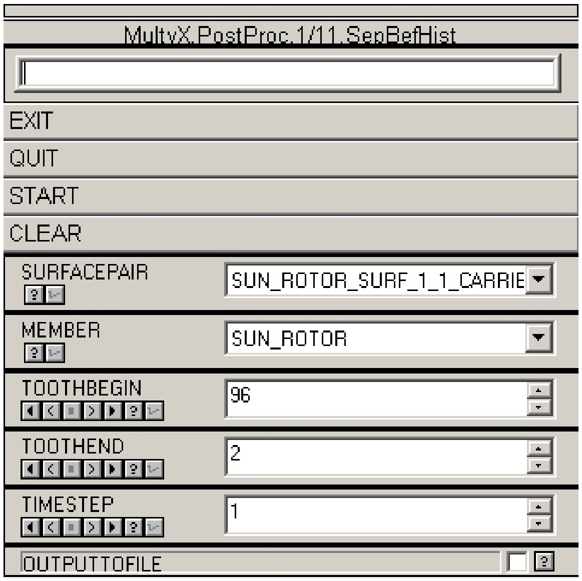


Figure 10.24 The grid pressure histogram generated by the GRIDPRHIST menu.



SURFACEPAIR SUN_ROTOR_SURF_1_1_CARRIE
MEMBER SUN_ROTOR
TOOTHBEGIN 96
TOOTHEND 2
TIMESTEP 1
OUTPUTTOFILE ☐

Figure 10.25 The SEPBEFHIST menu.

10.11 The SEPBEFHIST command

The SEPBEFHIST command in the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.25. This menu is used to to generate a histogram of the distribution of normal separation over individual contact grid cells, in the unloaded and undeformed state.

Figure 10.26 shows an example of a histogram of separation in the unloaded state. Negative separation values are possible in this histogram.

10.12 The SEPAFTHIST command

The SEPAFTHIST command in the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.27. This menu is used to to generate a histogram of the distribution of normal separation over individual contact grid cells, in the loaded and deformed state.

Figure 10.28 shows an example of a histogram of separation in the loaded state. These separation values must be either zero or positive.

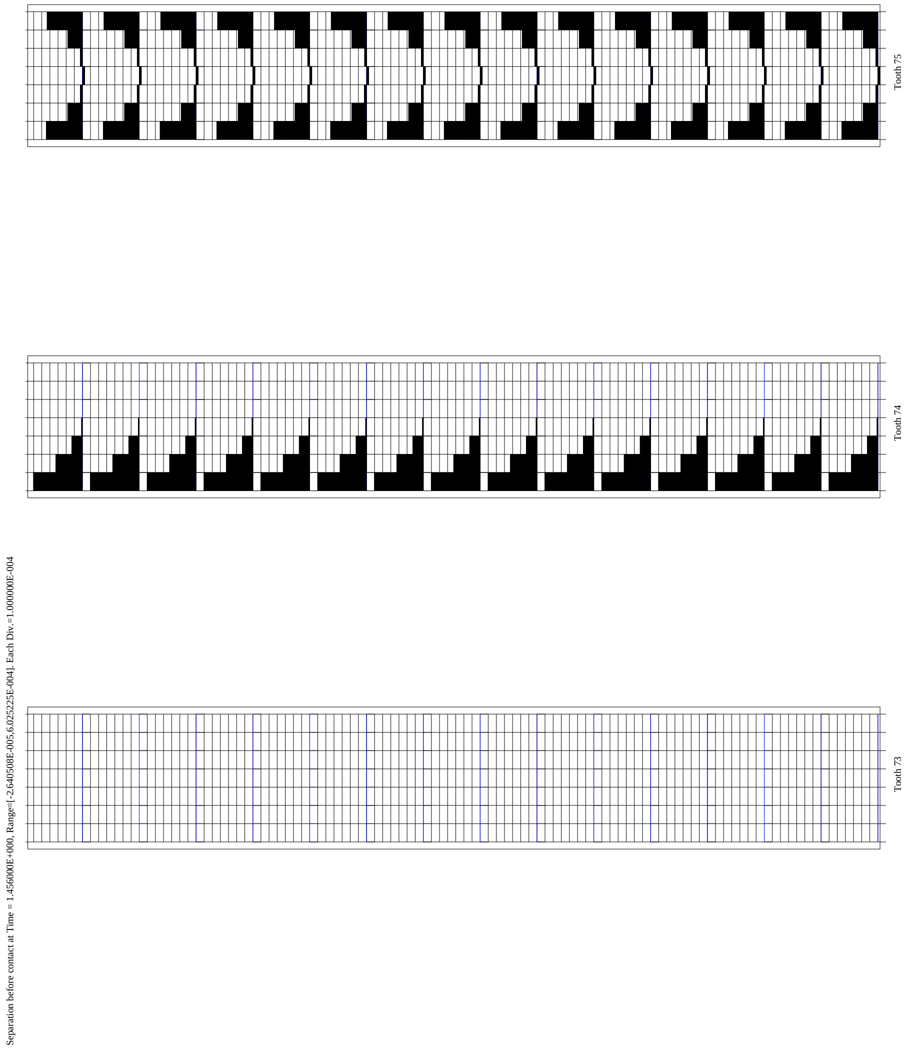
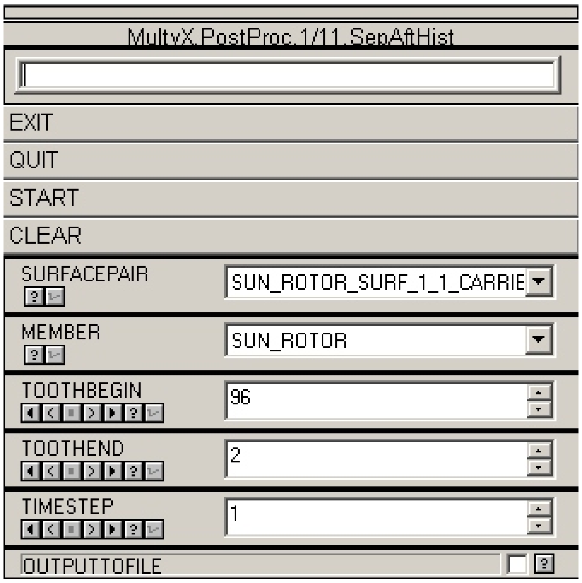


Figure 10.26 The histogram of grid separation before contact, generated by the SEPBEFHIST menu.


MultyX.PostProc.1/11.SepAftHist
EXIT
QUIT
START
CLEAR

SURFACEPAIR SUN_ROTOR_SURF_1_1_CARRIE

MEMBER SUN_ROTOR

TOOTHBEGIN 96

TOOTHEND 2

TIMESTEP 1

OUTPUTTOFILE ☐

Figure 10.27 The SEPAFTHIST menu.

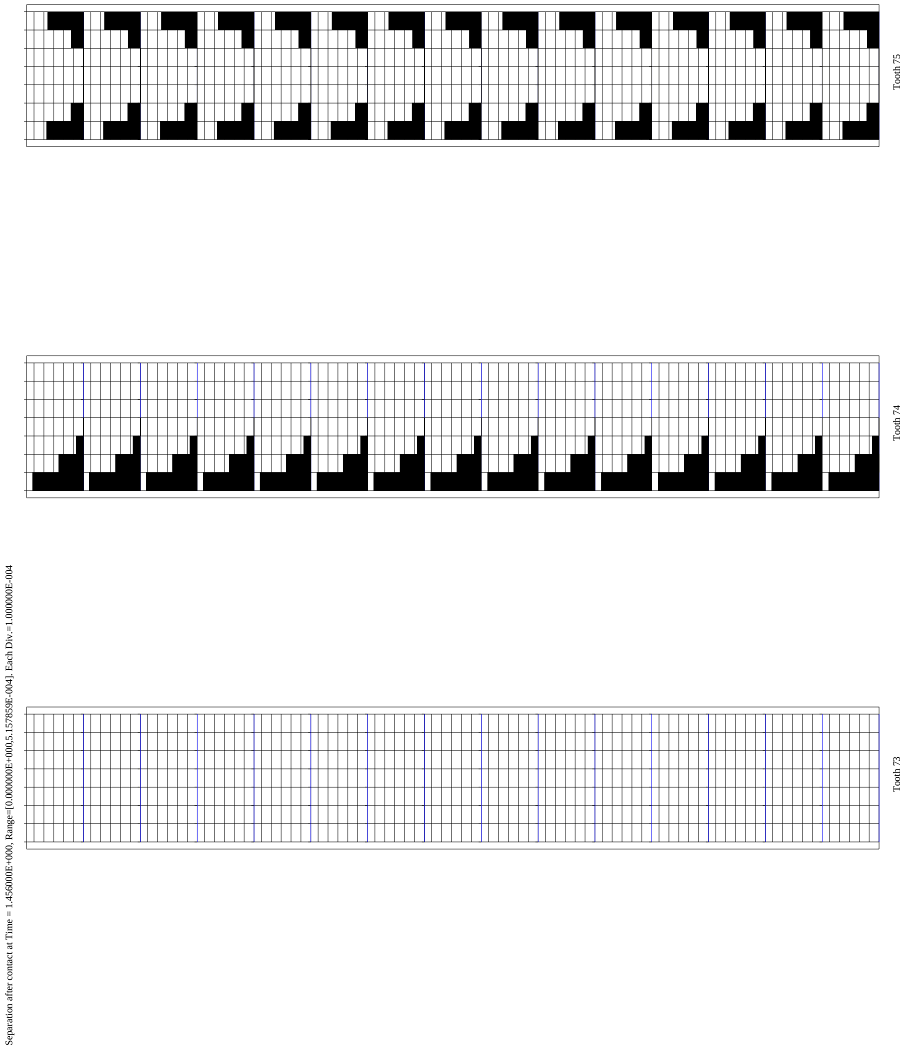


Figure 10.28 The histogram of grid separation after contact, generated by the SEPAFTHIST menu.

10.13 The SEARCHSTRESS command

The SEARCHSTRESS command of the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.29. This menu is used to locate the most critical stresses in the system.

The COMPONENT box is used to select the stress component of interest. Available choices are MAXPPLSTRESS (the maximum principal normal stress s_1), MINPPLSTRESS (the minimum principal normal stress s_3), MAXSHEAR (the maximum shear stress τ_{max}), and VONMISES (the Von Mises' octahedral shear stress s_{VM}).

Depending on selection in the XAXIS box, the stress can be displayed as a function of time (TIME), profile (SPROF), face (TFACE) or depth (DEPTH).

The stress values are computed over a range of time steps (specified by BEGINSTEP and ENDSTEP), teeth (specified by TOOTHBEGIN and TOOTHEND), location along the profile (specified by SPROFBEGIN, SPROFEND and NUMSPROF), location along the face (specified by TFACEBEGIN, TFACEEND and NUMTFACE), and depth (specified by DEPTHBEGIN, DEPTHEND and NUMDEPTH).

If the number of teeth in the range defined by TOOTHBEGIN and TOOTHEND is 7 or less, and if the SEPTEETH box is checked, then a separate graph is drawn for each tooth. Otherwise a single graph is drawn showing the most critical stress among all the teeth in the range.

Searching for stresses in the depth direction is a very compute intensive operation, so the number of points in the depth direction should be kept at 1 if possible. If a graph of stress vs. depth is desired, then the range of the other parameters should be restricted as much as possible.

File output is controlled by the OUTPUTTOFILE, FILENAME and APPEND items. Figure 10.30 shows an example of stress as a function of time, Figure 10.31 shows stress as a function of profile position. Sharp oscillations can be seen in this graph in the vicinity of the concentrated contact loads. Figure 10.32 shows a graph of stress vs. face.

10.14 The POINTSTRESS command

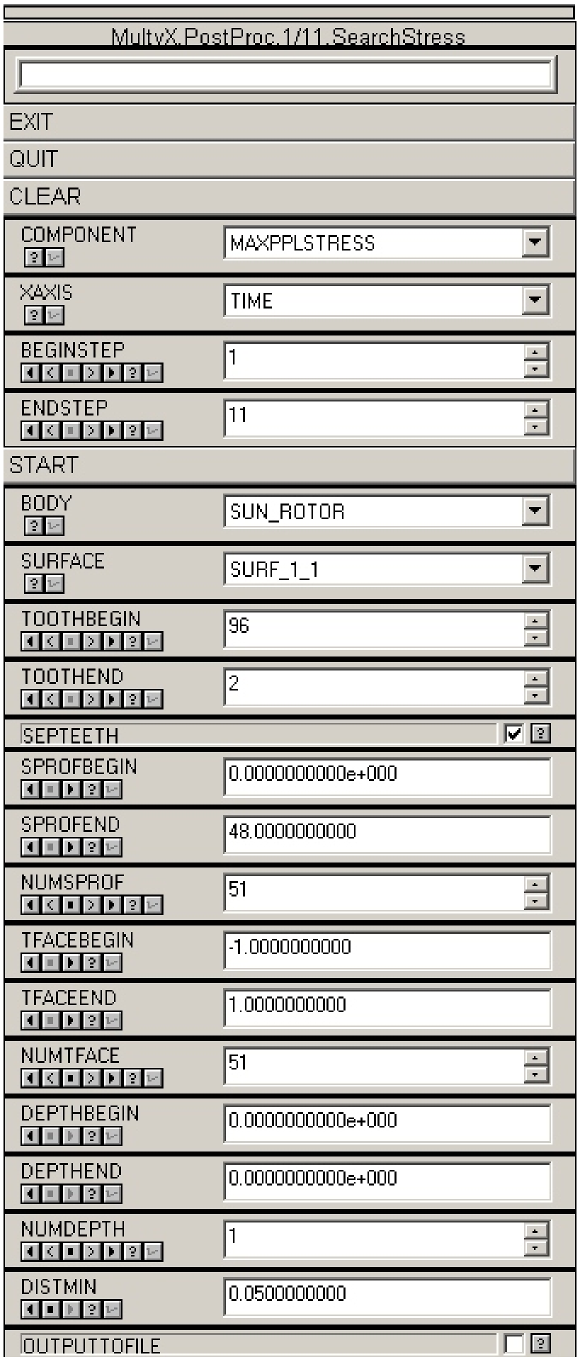
The POINTSTRESS command of the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.33. This menu is used to track normal stresses in a specific direction at a specific point on a surface.

The surface is selected by specifying the body in the BODY box and a surface in the SURFACE box. A range of teeth with up to 7 teeth is selected through the TOOTHBEGIN and TOOTHEND items. A profile and face location on this surface is specified through the SPROF and TFACE parameters.

The direction is specified by an angle in the item ANGLE. This angle is the angle between the normal direction of interest and the profile direction (if the REFDIRECTION option is SPROF) or the face direction (if the REFDIRECTION option is TFACE). The angle is measured using the right hand rule about the outward normal to the surface.

The range of time steps is specified by the BEGINSTEP and ENDSTEP items. File output is controlled by the OUTPUTTOFILE, FILENAME and APPEND items.

Figure 10.34 shows an example of the graph generated by this menu.


MultyX.PostProc.1/11.SearchStress
EXIT
QUIT
CLEAR
START

COMPONENT MAXPPLSTRESS

XAXIS TIME

BEGINSTEP 1

ENDSTEP 11

BODY SUN_ROTOR

SURFACE SURF_1_1

TOOTHBEGIN 96

TOOTHEND 2

SEPTEETH ☑

SPROFBEGIN 0.0000000000e+000

SPROFEND 48.0000000000

NUMSPROF 51

TFACEBEGIN -1.0000000000

TFACEEND 1.0000000000

NUMTFACE 51

DEPTHBEGIN 0.0000000000e+000

DEPTHEND 0.0000000000e+000

NUMDEPTH 1

DISTMIN 0.0500000000

OUTPUTTOFILE ☐

Figure 10.29 The SEARCHSTRESS menu

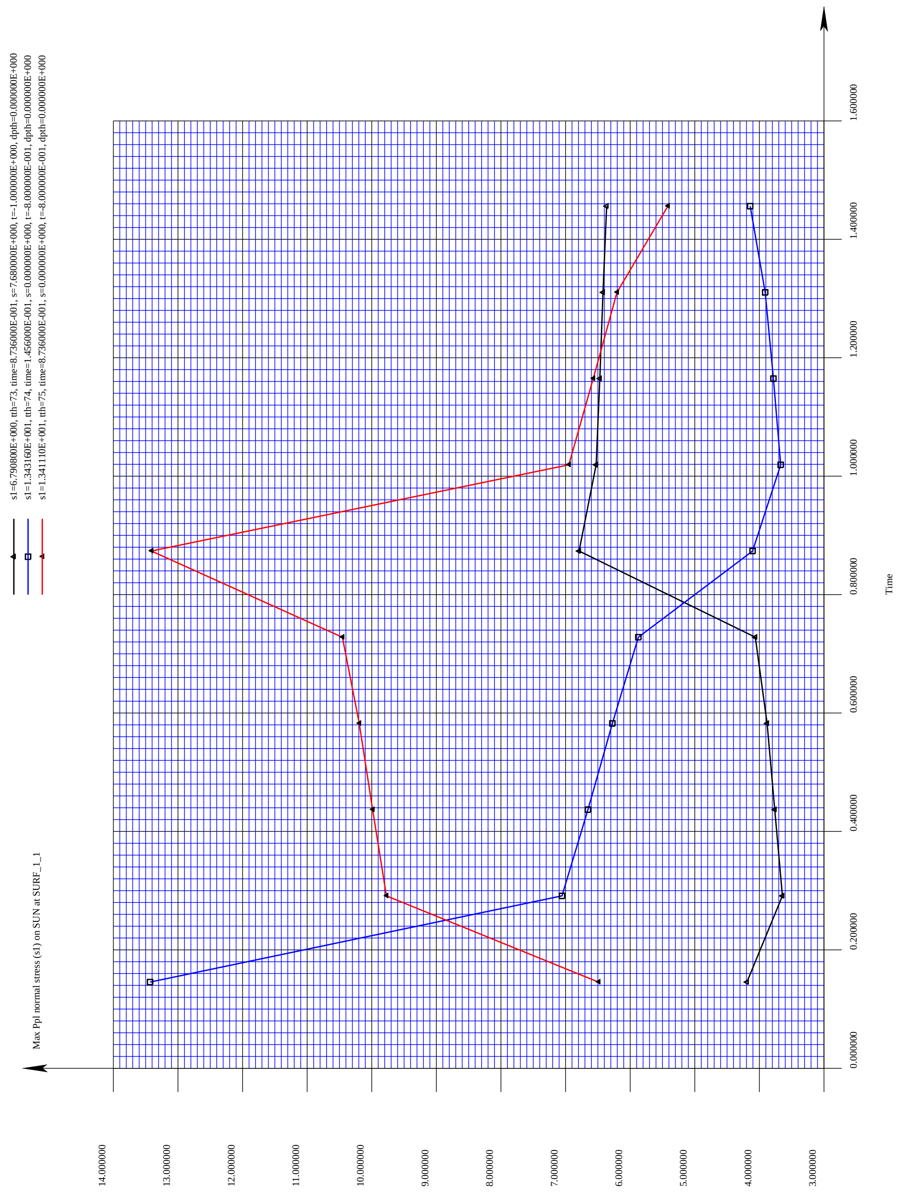


Figure 10.30 The graph of root stress vs. time, generated by the SEARCHSTRESS menu.

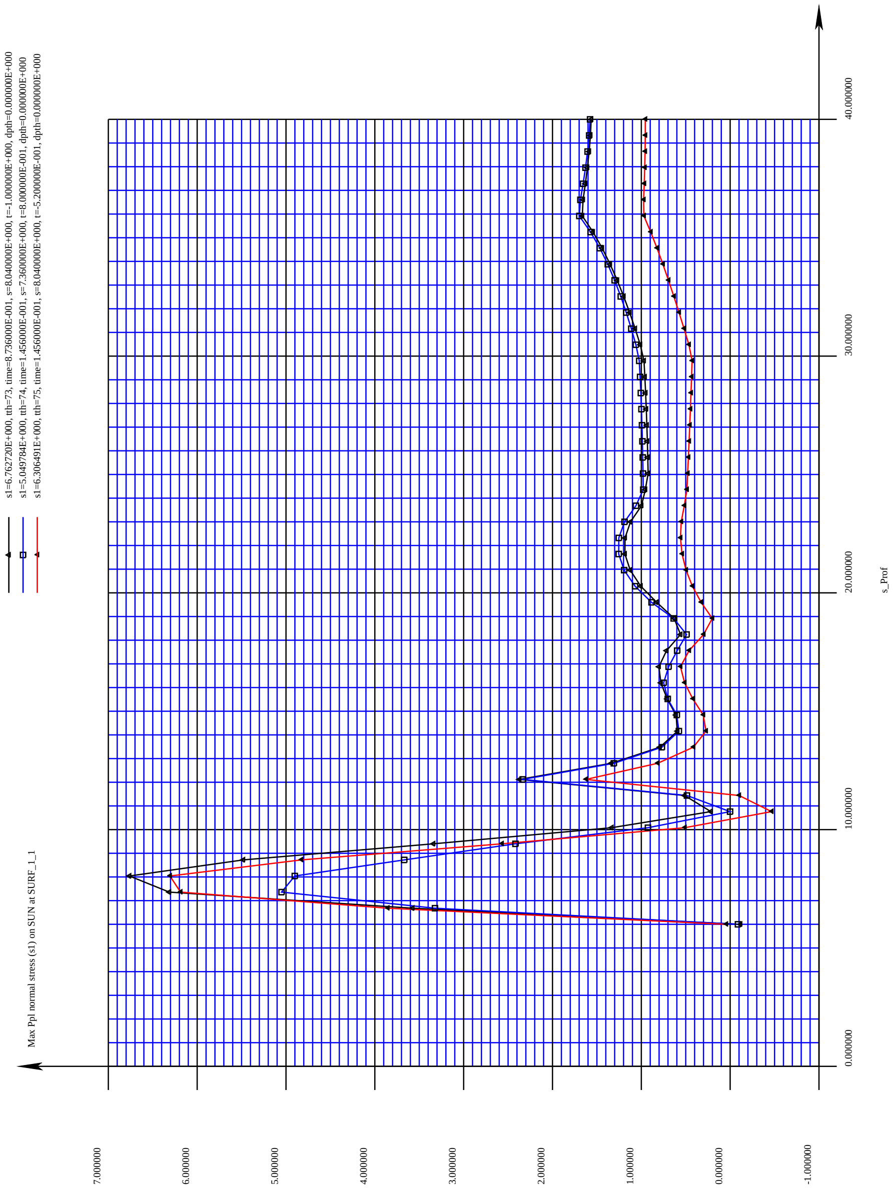


Figure 10.31 The graph of root stress vs. profile, generated by the SEARCHSTRESS menu.

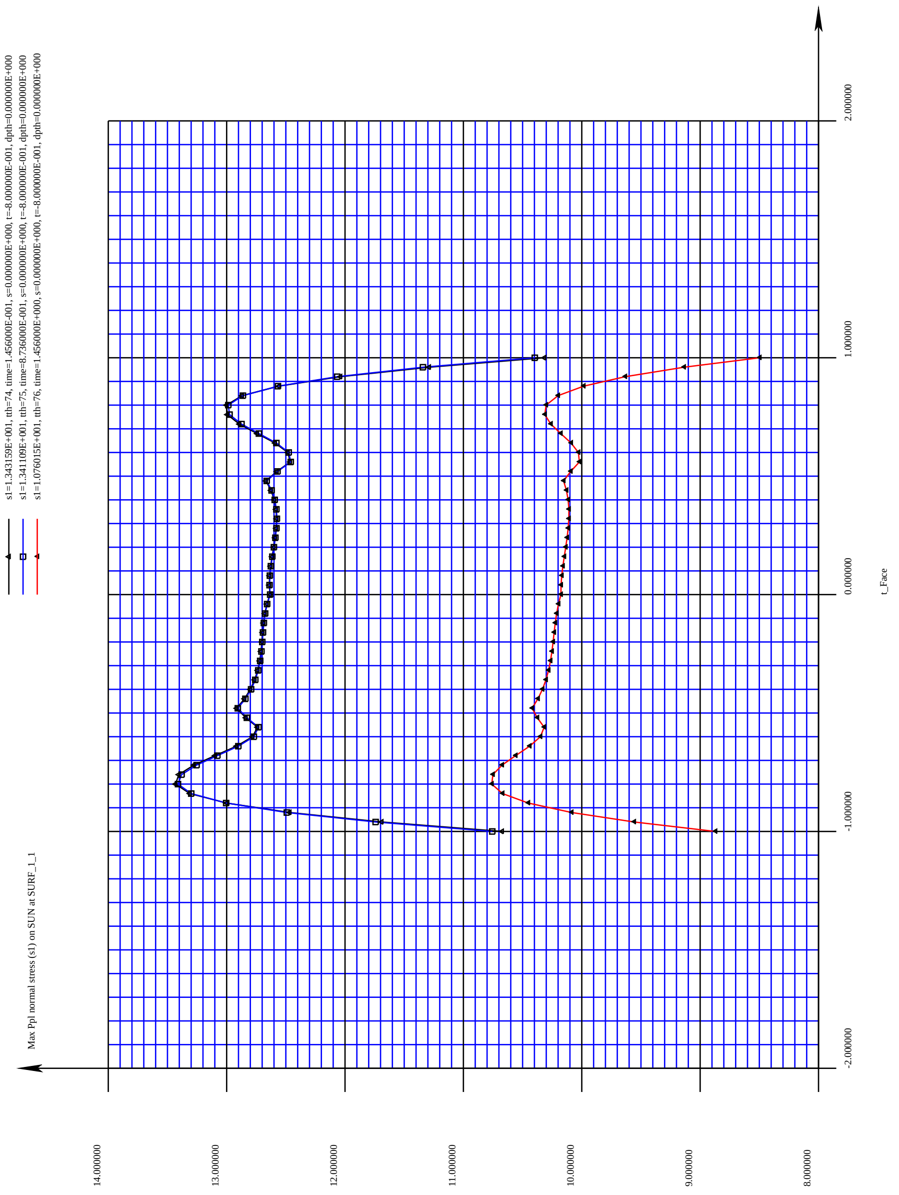
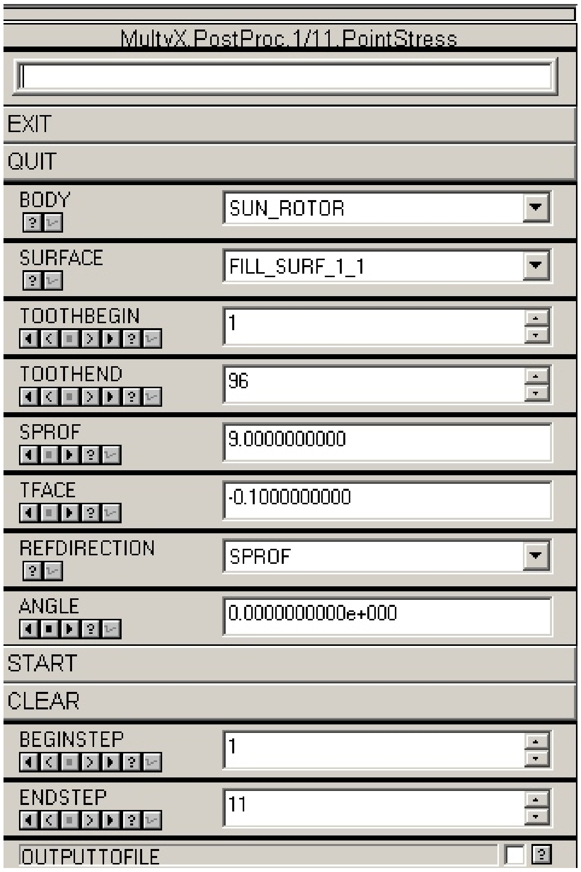


Figure 10.32 The graph of root stress vs. face, generated by the SEARCHSTRESS menu.



MultyX.PostProc.1/11.PointStress
EXIT
QUIT
START
CLEAR
OUTPUTTOFILE

BODY SUN_ROTOR

SURFACE FILL_SURF_1_1

TOOTHBEGIN 1

TOOTHEND 96

SPROF 9.0000000000

TFACE -0.1000000000

REFDIRECTION SPROF

ANGLE 0.0000000000e+000

BEGINSTEP 1

ENDSTEP 11

OUTPUTTOFILE ☐

Figure 10.33 The POINTSTRESS menu.

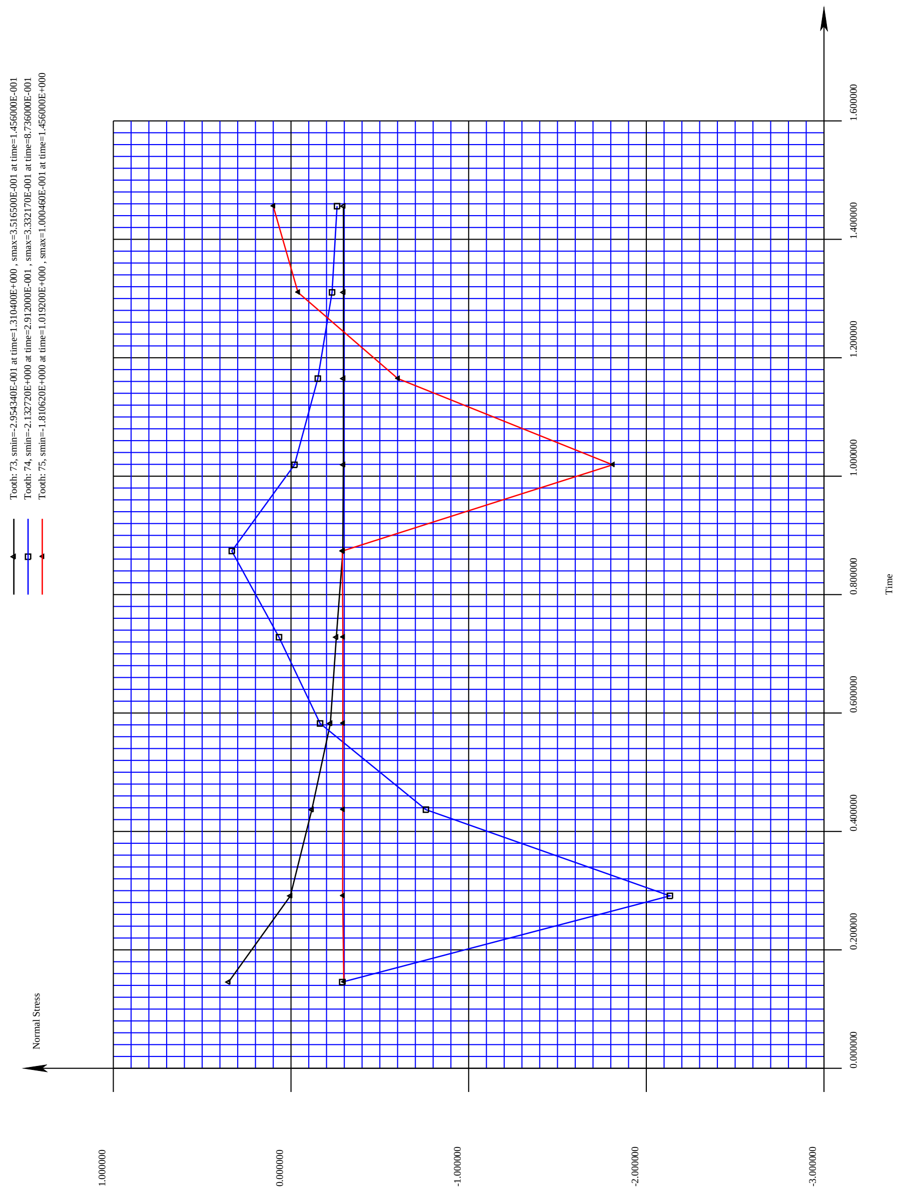


Figure 10.34 The graph of root stress vs. face, generated by the POINTSTRESS menu.

10.15 The PATTERN command

The PATTERN command of the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.35. This menu is used to draw color or contour distribution of contact pressure, flash temperature, specific film thickness on the tooth surface and surface wear.

The tooth surface is selected by choosing the gear pair in the SURFACEPAIR box and a member from the MEMBER drop down list. A range of teeth in contact is selected through the TOOTHBEGIN and TOOTHEND items. The range of time steps is specified by the BEGINSTEP and ENDSTEP items.

The parameters to be plotted is chosen in the PATTERNCOMPONET menu item. The distribution can be displayed in color if the COLORS box is checked, or with contour lines if the CONTOURS box is checked. At least one of them must be turned ON to draw the pattern.

The pattern drawing is not three-dimensional. It is a projection of the contact surface in the $r-z$ coordinate plane.

If the SMOOTH box is checked, then the pattern data will be smoothed by fitting a polynomial surface to the raw data.

If the FLIP box is checked, the orientation of the Z axis on the plot is flipped pointing towards left of the screen.By default, the Z axis points towards the right end of the screen.

The GRID option enables the user to overlay the *Transmission3D* parametric tooth surface, S&T coordinates on the pattern distribution.

To draw sliding velocity and rolling velocity on the pattern plot, the corresponding SLIDING VELOCITY and ROLLING VELOCITY checkbox must be turned ON. This draws a red arrow in the direction of the vector.

MODELUNITS will be the system of units used in setting up the model. This is needed to convert the stresses and gear material properties from model units to ISO standard units to calculate flash temperature and specific film thickness.

10.15.1 Contact Pattern

To draw the contact pattern,PATTERNCOMPONENT must be set to CONTACTPRESSURE and the PRESSURESTYPE is set to either CALYX or HERTZ. CALYX uses the contact grid based pressure values calculated in Transmission3D and HERTZ uses the Hertz formula along with the load intensity and relative curvatures.A sample contact pattern is shown in Figure 10.36.

10.15.2 Flash Temperature

The flash temperature is calculated based on the ISO standard, *ISO/TR 15144-1,Calculation of micropitting load capacity of cylindrical spur and helical gears* [19].To get a distribution of flash temperature at the contact surface, the PATTERNCOMPONENT is set to FLASHTEMP and set coefficient of friction MU, specific heat of conductivity ($LAMBDA\_SI$) and specific heat capacity(CP_SI)for the gears as shown in Figure 10.35.Since the ISO standard is based on SI units, gear thermal properties, specific heat capacity and conductivity must be given in SI units of J/kgK and W/mK respectively.

If SAMEMATERIAL flag is checked on, both the gears are modeled with same thermal properties. When turned OFF, independent material properties of two gear should be given.

The equation to calculate the flash temperature is stated below,

$$\theta_f = \frac{\sqrt{\pi}}{2}\frac{10^6.\mu.H_s.|V_s|}{B_{M1}\sqrt{V_{r1}}+B_{M2}\sqrt{V_{r2}}}\sqrt{8\kappa\frac{H_s}{1000E_r}}$$

where,

$$B_{M1} = \sqrt{\rho_{M1}.\lambda_{M1}.c_{M1}}$$
$$B_{M2} = \sqrt{\rho_{M2}.\lambda_{M2}.c_{M2}}$$
$$E_r = 2\left(\frac{1-{\nu_1}^2}{E_1} + \frac{1-{\nu_2}^2}{E_2}\right)^{-1}$$

θ_f - Flash Temperature, Celsius
μ - Coefficient of friction
B_{M1}, B_{M2} - Thermal Coefficient of member 1 and member 2
$\lambda_{M1}, \lambda_{M2}$ - Specific heat conductivity of member 1 and member 2, (Default: 45 W/mK)
c_{M1}, c_{M2} - Specific heat capacity of member 1 and member 2,(Default: 440 J/kgK)
ρ_{M1}, ρ_{M2} - Density of member 1 and member 2, kg/m^3
E_1, E_2 - Young's Modulus of member 1 and member 2,N/mm^2
ν_1, ν_2 - Poisson's Ratio of member 1 and member 2
E_r - Reduced Modulus of Elasticity, N/mm^2
H_s - Contact pressure, N/mm^2
V_s - Sliding velocity, m/s
V_{r1}, V_{r2} - Rolling velocity of member 1 and member 2, m/s
κ - Normal radius of relative curvature, mm

Coefficient of Friction When $AUTOCOMPUTE\_MU$ flag is turned ON, instantaneous coefficient of friction is computed using the following equation based on the ISO standard. The factors compensating for the nominal load and dynamic factor is assumed to be 1.0 in the equation.

$$\mu = 0.045\left(\frac{K_A.K_V.K_{H\alpha}.K_{H\beta}.K_{H\gamma}.L_I}{V_r.\kappa}\right)^{0.2}\left(10^3.\eta_{\theta M}\right)^{-0.05} X_R X_L$$

where,

$$X_R = 2.2\left(\frac{R_a}{\kappa}\right)^{0.025}$$
$$X_L = 1.0$$
$$K_A, K_V, K_{H\alpha}, K_{H\beta}, K_{H\gamma} = 1.0$$

X_R - Roughness Factor
L_I - Load Intensity, N/mm
V_r - Sum of rolling velocities $(V_{r1} + V_{r2})$, m/s
κ - Normal radius of relative curvature, mm
θ_M - Bulk temperature, Celsius
$\eta_{\theta M}$ - Dynamic viscosity at bulk temperature, Ns/m^2
K_A - Application factor
K_V - Dynamic factor
$K_{H\alpha}$ - Transverse load factor
$K_{H\beta}$ - Face load factor
$K_{H\gamma}$ - Helical load factor
X_L - Lubrication factor

10.15.3 Film Thickness

The FILMTHICKNESS pattern component calculates the specific lubricant film thickness at the contact surface. This is also calculated based on the formulation from ISO standard 15144-1 [19]. The equations used to calculate the film thickness are listed below, for detailed explanation of all parameters please refer to the standard. The additional inputs needed for lubricant film thickness calculations are

1. $ALPHA\_SI$,Pressure Viscosity Coefficient of the lubricant at 38 C, m^2/N
2. ETA_40_METRIC,Kinematic Viscosity of the lubricant at 40 C, mm^2/s
3. ETA_100_METRIC,Kinematic Viscosity of the lubricant at 100 C, mm^2/s
4. $DENSITY_15_SI$Density of the lubricant at 15 C, kg/m^3
5. $BULKTEMP$,Bulk Temperature, Celsius
6. RA_SI,Effective arithmetic mean surface roughness of the gears, μm

$$h_s = \frac{h_y}{R_a}$$

$$h_y = 1600.\kappa.{G_M}^{0.6}.{U_Y}^{0.7}.{W_Y}^{-0.13}.{S_Y}^{0.22}$$

where,

h_s - Local Specific Film Thickness
h_y - Local Film thickness, μm
R_a - Effective arithmetic mean roughness value, μm
G_M - Material parameter
U_Y - Local Velocity parameter
W_Y - Local Load parameter
S_Y - Local Sliding parameter

Material parameter

$$G_M = 10^6.\alpha_{\theta M}.E_r$$

$$\alpha_{\theta m} = \alpha_{38} * \left[1 + 516\left(\frac{1}{\theta_M + 273} - \frac{1}{311}\right)\right]$$

where,

α_{38} - Pressure viscosity coefficient of the lubricant at 38 C, m^2/N
θ_M - Bulk temperature, Celsius

Local velocity parameter

$$U_Y = \eta_{\theta M}\frac{V_r}{2000.E_r.\kappa}$$

$$\eta_{\theta M} = 10^{-6}.\nu_{\theta M}.\rho_{\theta M}$$

where,

$\eta_{\theta M}$ - Dynamic viscosity at bulk temperature, Ns/m^2
V_r - Sum of rolling velocities $(V_{r1} + V_{r2})$, m/s
$\nu_{\theta M}$ - Kinematic viscosity at bulk temperature, mm^2/s
$\rho_{\theta M}$ - Density of lubricant at bulk temperature, kg/m^3

$$\nu_{\theta M} = 10^{10^{A.log(\theta_M+273)+B}} - 0.7$$

where,

$$A = \frac{log[log(\nu_{40}+0.7)/log(\nu_{100}+0.7)]}{log(313/373)}$$
$$B = log[log(\nu_{40}+0.7)] - A.log313$$

ν_{40} - Kinematic viscosity at 40 C, mm^2/s

ν_{100} - Kinematic viscosity at 100 C, mm^2/s

$$\rho_{\theta M} = \rho_{15}.\left[1 - 0.7.\frac{(\theta_M+273)-289}{\rho_{15}}\right]$$

ρ_{15} - Density of Lubricant at 15 C, kg/m^3

Local load parameter

$$W_Y = \frac{2.\pi.{H_s}^2}{{E_r}^2}$$

where,

H_s - Local Contact Stress, N/mm^2

E_r - Reduced modulus of elasticity, N/mm^2

Local sliding parameter

$$S_G = \frac{\alpha_{\theta B}.\eta_{\theta B}}{\alpha_{\theta M}.\eta_{\theta M}}$$
$$\theta_B = \theta_M + \theta_f$$

where,

$\alpha_{\theta B}$ - Pressure viscosity coefficient of the lubricant at contact temperature, m^2/N

$\alpha_{\theta M}$ - Pressure viscosity coefficient of the lubricant at bulk temperature, m^2/N

$\eta_{\theta B}$ - Dynamic viscosity of the lubricant at contact temperature, Ns/m^2

$\eta_{\theta M}$ - Dynamic viscosity of the lubricant at bulk temperature, Ns/m^2

θ_B - Contact temperature, Celsius

Safety factor against micropitting The micropitting safety factor according to the ISO standard [19] is given by the equation

$$S_{contact} = \frac{h_{s,min}}{h_{sp}}$$

where,

$h_{s,min} = min(h_s)$ - Minimum specific lubricant film thickness in the contact area

h_{sp} - Permissible specific lubricant film thickness

10.15.4 Wear

The surface wear is another important parameter for studying gear pitting failures. The wear is calculated based on Archard's wear equation as given below

$$\frac{dw}{ds} = kP \qquad (10.1)$$

Assuming sliding velocity and contact pressure distribution remains constant,

$$w = k \int P(t) v_s(t) dt$$
$$w = k v_s \int \frac{P(t)}{\frac{dx}{dt}} dx$$
$$w = k \frac{v_s}{v_r} \int P(x) dx$$

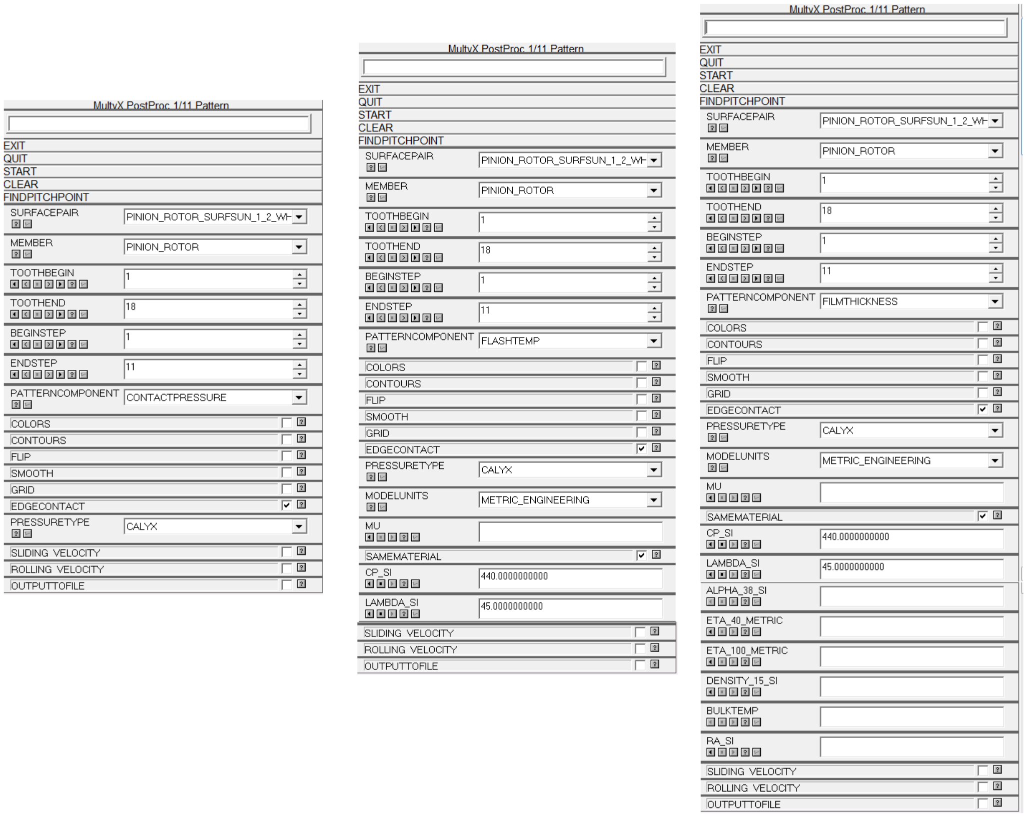
For a parabolic pressure distribution,

$$w = \frac{4}{3} k \frac{v_s}{v_r} P.l$$

where,

w - Wear per unit cycle, m
k - Wear Coefficient, m^2/N (Default: 9.65e-19 m^2/N)
P - Contact stress, N/m^2
l - Hertzian Semiwidth, m
v_s - Sliding velocity, m/s
v_r - Rolling velocity, m/s

To calculate the wear , set PATTERNCOMPONENT to WEAR and provide the number of cycles of gear and wear coefficient. The wear coefficient is default to 9.65e-19 based on study done in reference [20]


MultyX PostProc 1/11 Pattern
EXIT
QUIT
START
CLEAR
FINDPITCHPOINT

SURFACEPAIR PINION_ROTOR_SURFSUN_1_2_WH
MEMBER PINION_ROTOR
TOOTHBEGIN 1
TOOTHEND 18
BEGINSTEP 1
ENDSTEP 11
PATTERNCOMPONENT CONTACTPRESSURE
COLORS ☐
CONTOURS ☐
FLIP ☐
SMOOTH ☐
GRID ☐
EDGECONTACT ☑
PRESSURETYPE CALYX
SLIDING VELOCITY ☐
ROLLING VELOCITY ☐
OUTPUTTOFILE ☐

MultyX PostProc 1/11 Pattern
EXIT
QUIT
START
CLEAR
FINDPITCHPOINT

SURFACEPAIR PINION_ROTOR_SURFSUN_1_2_WH
MEMBER PINION_ROTOR
TOOTHBEGIN 1
TOOTHEND 18
BEGINSTEP 1
ENDSTEP 11
PATTERNCOMPONENT FLASHTEMP
COLORS ☐
CONTOURS ☐
FLIP ☐
SMOOTH ☐
GRID ☐
EDGECONTACT ☑
PRESSURETYPE CALYX
MODELUNITS METRIC_ENGINEERING
MU
SAMEMATERIAL ☑
CP_SI 440.0000000000
LAMBDA_SI 45.0000000000
SLIDING VELOCITY ☐
ROLLING VELOCITY ☐
OUTPUTTOFILE ☐

MultyX PostProc 1/11 Pattern
EXIT
QUIT
START
CLEAR
FINDPITCHPOINT

SURFACEPAIR PINION_ROTOR_SURFSUN_1_2_WH
MEMBER PINION_ROTOR
TOOTHBEGIN 1
TOOTHEND 18
BEGINSTEP 1
ENDSTEP 11
PATTERNCOMPONENT FILMTHICKNESS
COLORS ☐
CONTOURS ☐
FLIP ☐
SMOOTH ☐
GRID ☐
EDGECONTACT ☑
PRESSURETYPE CALYX
MODELUNITS METRIC_ENGINEERING
MU
SAMEMATERIAL ☑
CP_SI 440.0000000000
LAMBDA_SI 45.0000000000
ALPHA_38_SI
ETA_40_METRIC
ETA_100_METRIC
DENSITY_15_SI
BULKTEMP
RA_SI
SLIDING VELOCITY ☐
ROLLING VELOCITY ☐
OUTPUTTOFILE ☐

Figure 10.35 The PATTERN menu.

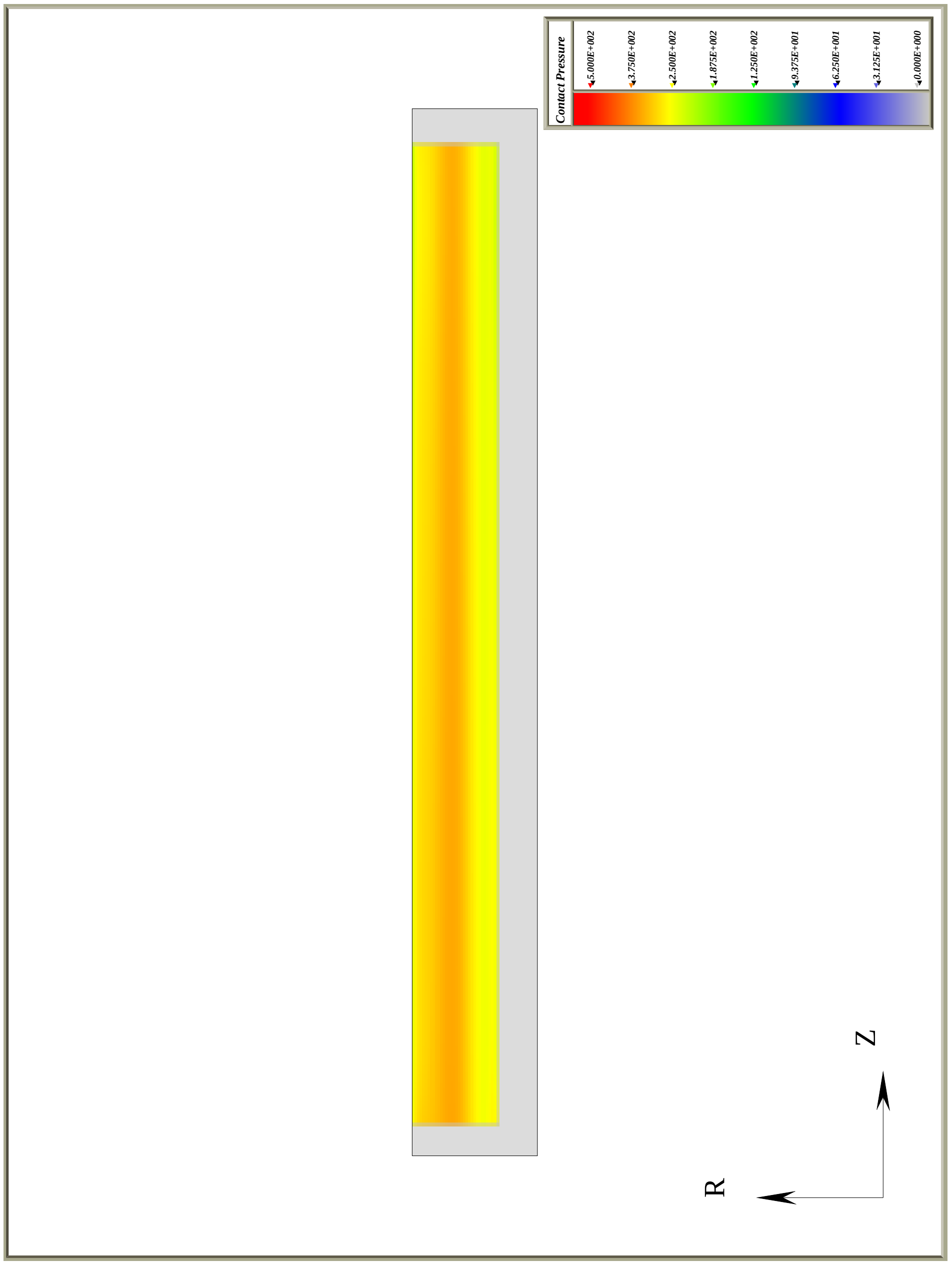


Figure 10.36 The contact pattern generated by the PATTERN menu.

10.16 The AUDIT command

Frequently the user needs to obtain the force and moment balance for the individual bodies in the system. The AUDIT command of the post-processing menu (Figure 10.3) generates an equilibrim ‘audit’ of all the forces and moments acting on each body. Figure 10.37 shows the AUDIT sub-menu. The list of bodies for which this audit is to be generated is selected through a sub-menu accessed through the SELECT button in this menu. The range if time steps is specified in the BEGINSTEP and ENDSTEP boxes.

The START button then displays the audit statement in the Information window. It can also be sent to an ASCII file by using the OUTPUTTOFILE, FILENAME and APPEND boxes.

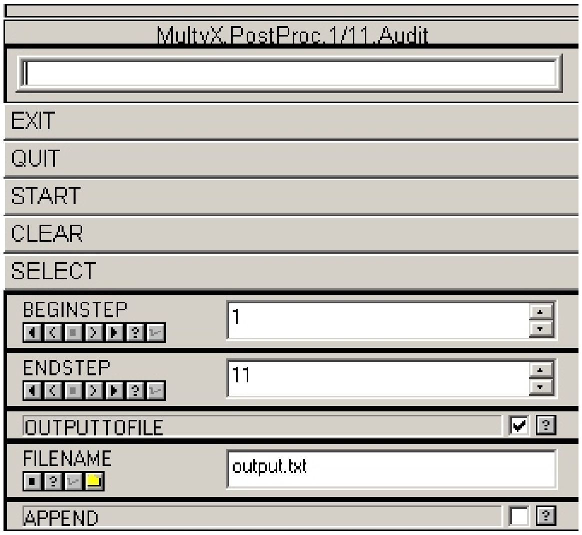
A sample equilibrium audit for the pinion shaft is shown below:

```
Time=-0.4
Body no.2:PINIONSHAFT (Origin at:[0,-1,0])
==================================================================

Contact forces:
    Exerted by:PINION
    Total  :f [-974.3496506,-360.2120942,-1.704639161e-012],
            mo[310.218819,-837.6780654,1000]
            m [310.218819,-837.6780654,25.65034942]
Total contact force=f [-974.3496506,-360.2120942,-1.704639161e-012]
                    mo[310.218819,-837.6780654,1000]
                    m [310.218819,-837.6780654,25.65034942]


Bearing forces:
Total bearing force=f [0,0,0],
                    mo[0,0,0]
                    m [0,0,0]


Total internal force (inertial+press+body):f [0,0,0],
                                           mo[0,0,0]
                                           m [0,0,0]
Total mass & damping force                :f [0,0,0],
                                           mo[0,0,0]
                                           m [0,0,0]
Total contact  force                      :f [-974.3496506,-360.2120942,-1.704639161e-012],
                                           mo[310.218819,-837.6780654,1000]
                                           m [310.218819,-837.6780654,25.65034942]
Total bearing  force                      :f [0,0,0],
                                           mo[0,0,0]
                                           m [0,0,0]
Total reaction force                      :f [974.3496506,360.2120942,1.704639161e-012],
                                           mo[-310.218819,837.6780654,-1000]
                                           m [-310.218819,837.6780654,-25.65034942]
==================================================================================
Residual force (error)                    :f [-5.684341886e-013,0,0],
                                           mo[-5.684341886e-014,1.136868377e-013,-1.813305062e-010]
                                           m [-5.684341886e-014,1.136868377e-013,-1.818989404e-010]
```

The forces (and moments) are broken down into contact forces, bearing forces, internal forces, mass and damping forces and reaction forces. The reaction forces are the forces exerted by the reference frame constraints.

Two values for the moments are displayed. In the above example, `mo` refers to the moments computed about the origin of the pinion shaft body. `m` stands for the moment computed about the origin of the fixed reference frame. The moments about the fixed reference frame are more useful in comparing the action and reaction acting on different bodies.

Regardless of the origin about which the moments are computed, the X Y and Z components of each force and moment always refer to the fixed reference frame.


MultyX.PostProc.1/11.Audit
EXIT
QUIT
START
CLEAR
SELECT

BEGINSTEP 1

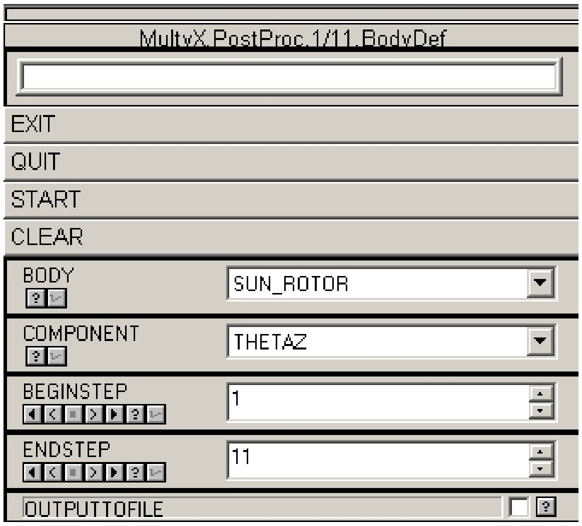
ENDSTEP 11

OUTPUTTOFILE ☑

FILENAME output.txt

APPEND ☐

Figure 10.37 The AUDIT menu.



BODY: SUN_ROTOR

COMPONENT: THETAZ

BEGINSTEP: 1

ENDSTEP: 11

OUTPUTTOFILE ☐

Figure 10.38 The BODYDEFLECTION menu.

10.17 The BODYDEFLECTION command

The BODYDEFLECTION command of the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.38. This menu is used to generate a graph (Figure 10.39) of a component of the rigid body type motion of a body as a function of time. The six components of motion that can be graphed are the 3 translation motions u_x, u_y and u_z, and the three rotation components θ_x, θ_y and θ_z. These components are calculated in the reference frame attached to the body. The rotation components are displayed in $Radians$.

10.18 The BODYREACTION command

The BODYREACTION command of the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.40. This menu is used to generate a graph (Figure 10.41) of a component of the body frame reaction as a function of time. The six force components that can be graphed are the three forces F_x, F_y and F_z, and the three moments M_x, M_y and M_z. These components are calculated in the reference frame attached to the body. The moments are computed about origin of this reference frame.

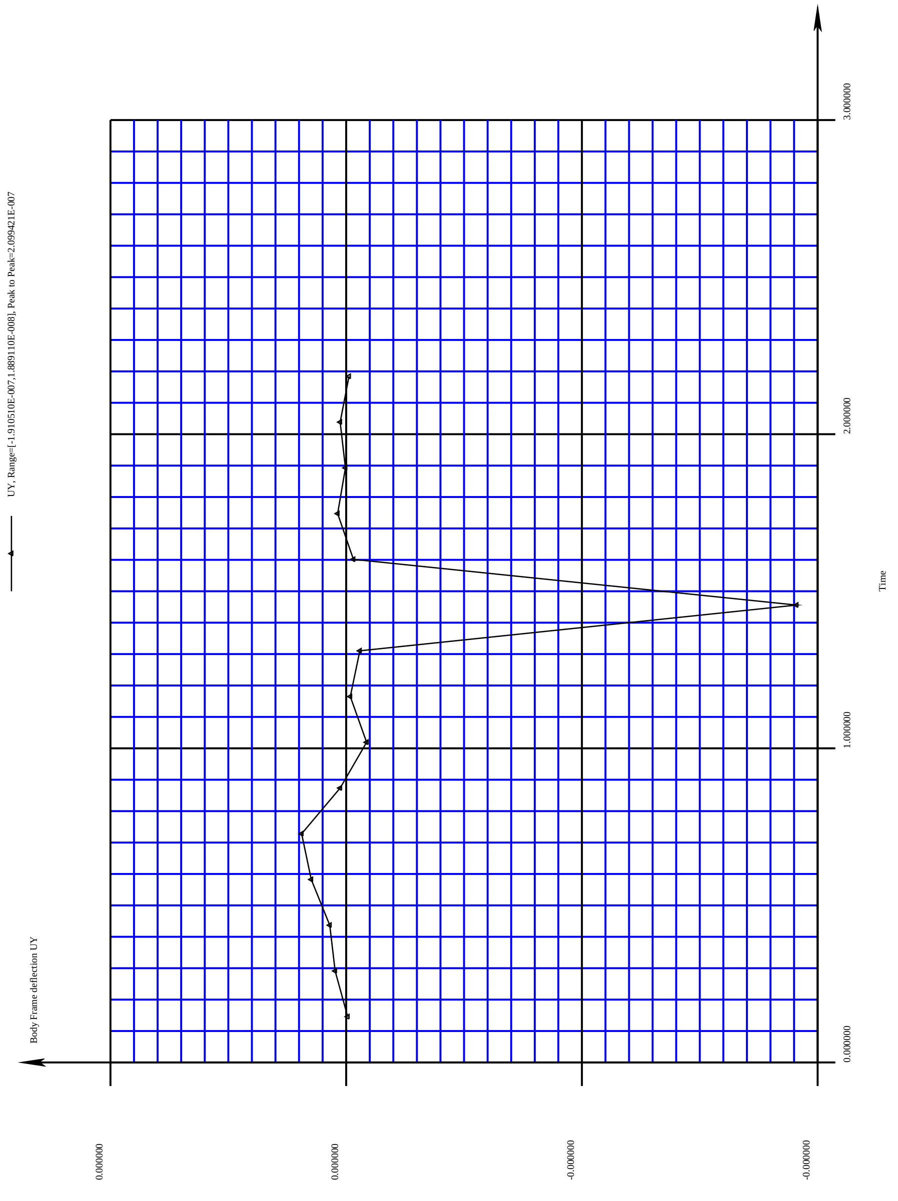
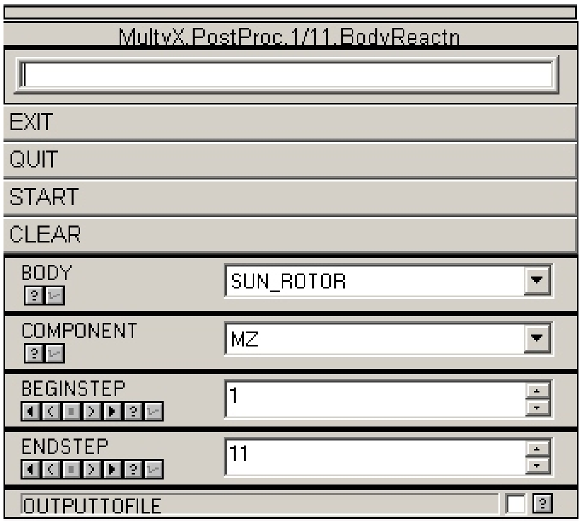


Figure 10.39 The graph generated by the BODYDEFLECTION menu.


MultyX.PostProc.1/11.BodyReactn
EXIT
QUIT
START
CLEAR

BODY SUN_ROTOR

COMPONENT MZ

BEGINSTEP 1

ENDSTEP 11

OUTPUTTOFILE ☐

Figure 10.40 The BODYREACTION menu.

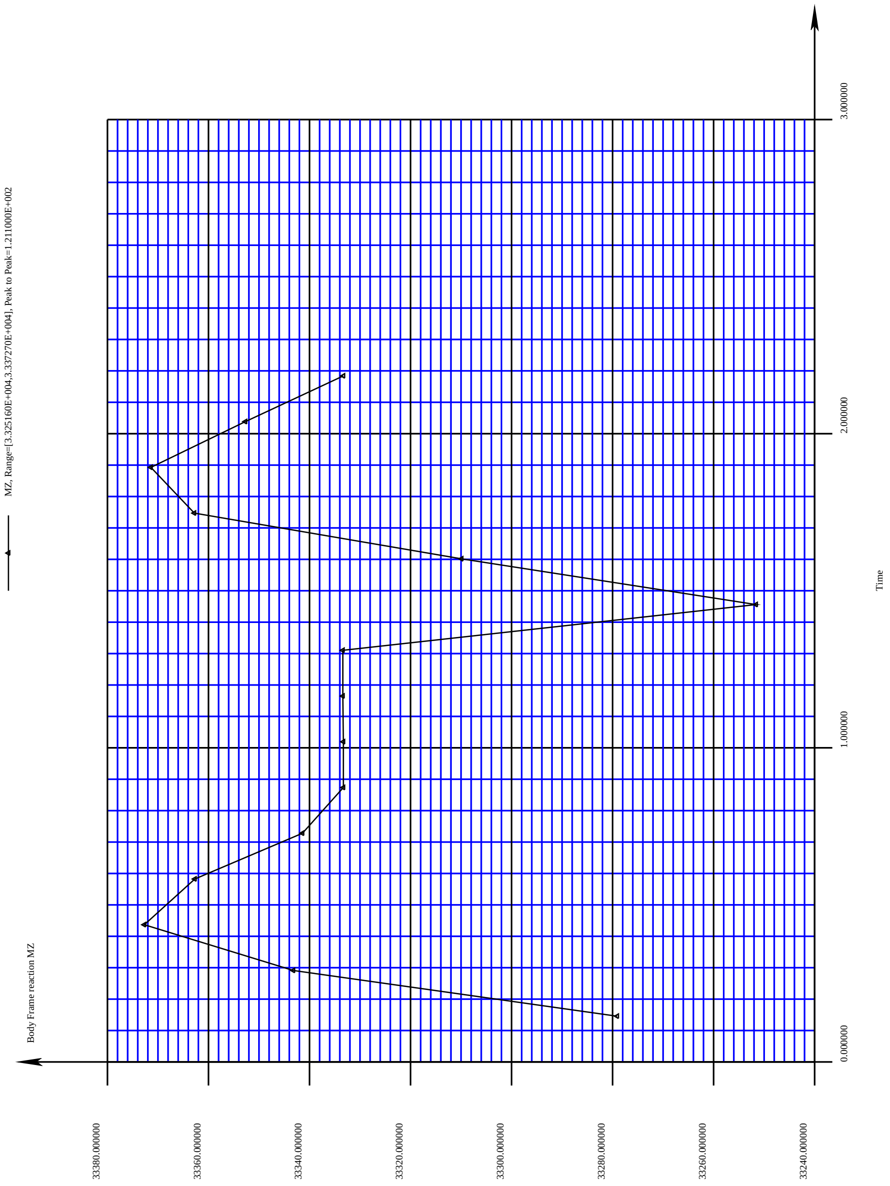
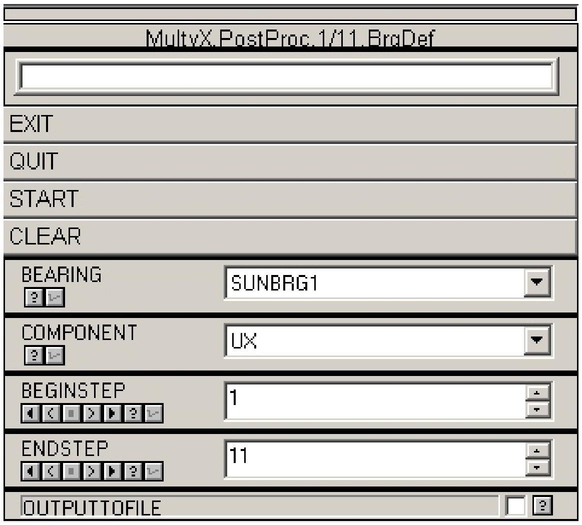


Figure 10.41 The graph generated by the BODYREACTION menu.



BEARING: SUNBRG1
COMPONENT: UX
BEGINSTEP: 1
ENDSTEP: 11
OUTPUTTOFILE ☐

Figure 10.42 The BRGDEFORMN menu.

10.19 The BRGDEFORMN command

The BRGDEFORMN command of the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.42. This menu is used to generate a graph (Figure 10.43) of a component of the bearing deformation as a function of time. The six components of motion that can be graphed are the 3 translation motions u_x, u_y and u_z, and the 3 rotation components θ_x, θ_y and θ_z of bearing race 1 with respect to bearing race 2. The components are measured in bearing race 2. In *Transmission3D*, bearing race 2 for the pinion and gear bearings are attached to the fixed body (ground). So the components are the same as they would appear when measured in the fixed frame.

The rotation components are displayed in $Radians$.

10.20 The BRGREACTION command

The BRGREACTION command of the post-processing menu (Figure 10.3) leads to the menu shown in Figure 10.44. This menu is used to generate a graph (Figure 10.45) of a component of the bearing reaction as a function of time. The six force components that can be graphed are the three forces F_x, F_y and F_z, and the three moments M_x, M_y and M_z. These components are the forces and moments exerted by race 1 on race 2. The components are calculated in the race 2 reference frame. The moments are about the origin of race 2. In *Transmission3D*, race 2 for the pinion bearing, as well as for the gear bearing is attached to the fixed body (ground). So the components are the same as they would appear when measured in the fixed reference frame.

10.21 The BRGPATTERN command

The BRGPATTERN command of the post-processing menu (Figure 10.3) leads to the menu shown in Figure **??**. This menu is used to generate a contact pattern (Figure 10.47) of the roller length (Z) as a function of angular position T. The contact pattern can be generated for the contact between the roller contact with the INNER or OUTER race and can be generated for any number of time steps. There are three PATTERNCOMPONENTS that can be generated: CONTACPRESSURE, SUBSURFACESHEAR, and SUBSURFACEVONMISES. The COLORS option generates the pattern in color. CONTOURS draws the pattern with contour lines at a specified DELTAPRESS value. For both the COLORS and CONTOURS options, MINPRESS and MAXPRESS values are also required. The FLIP option flips the orientation of the z-axis in the pattern, and GRID turns on a mesh grid which is overlayed on top of the pattern. PRESSURETYPE

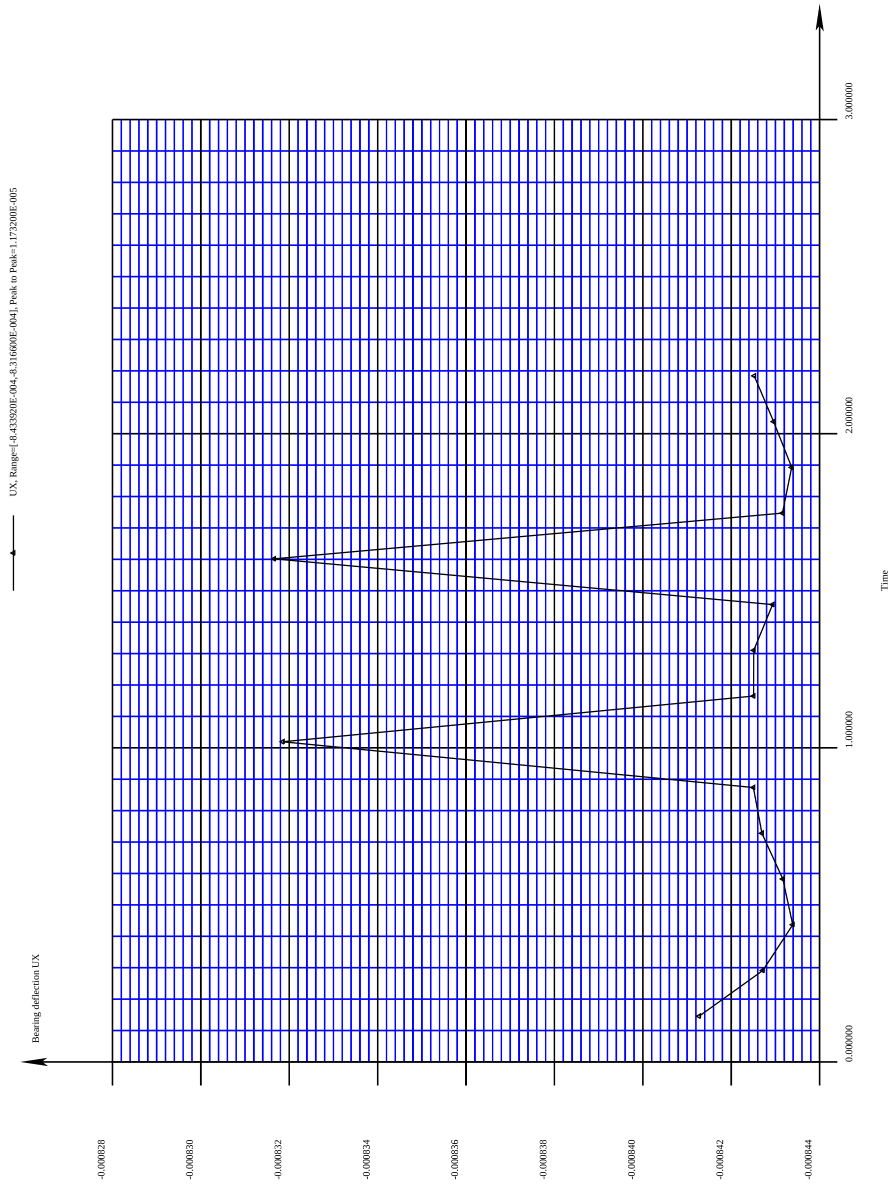
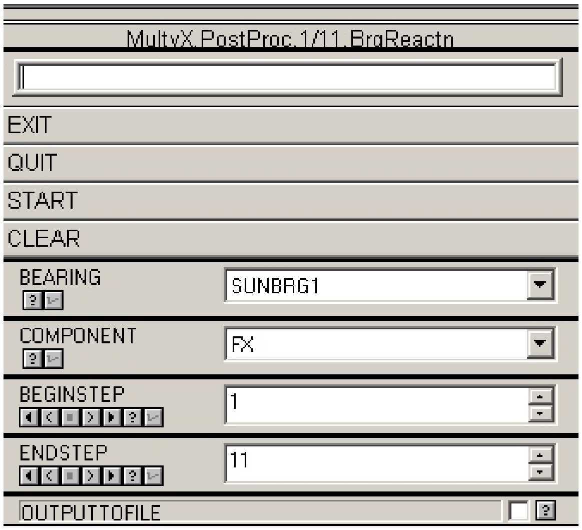


Figure 10.43 The graph generated by the BRGDEFORMN menu.



BEARING: SUNBRG1

COMPONENT: FX

BEGINSTEP: 1

ENDSTEP: 11

Figure 10.44 The BRGREACTION menu.

can be set to CALYX or HERTZ for the contact pressure and sub surface shear components. The OUTPUTTOFILE switch allows the pattern data to be output to a text file specified in the FILENAME input field.

These components are the forces and moments exerted by race 1 on race 2. The components are calculated in the race 2 reference frame. The moments are about the origin of race 2. In *Transmission3D*, race 2 for the pinion bearing, as well as for the gear bearing is attached to the fixed body (ground). So the components are the same as they would appear when measured in the fixed reference frame.

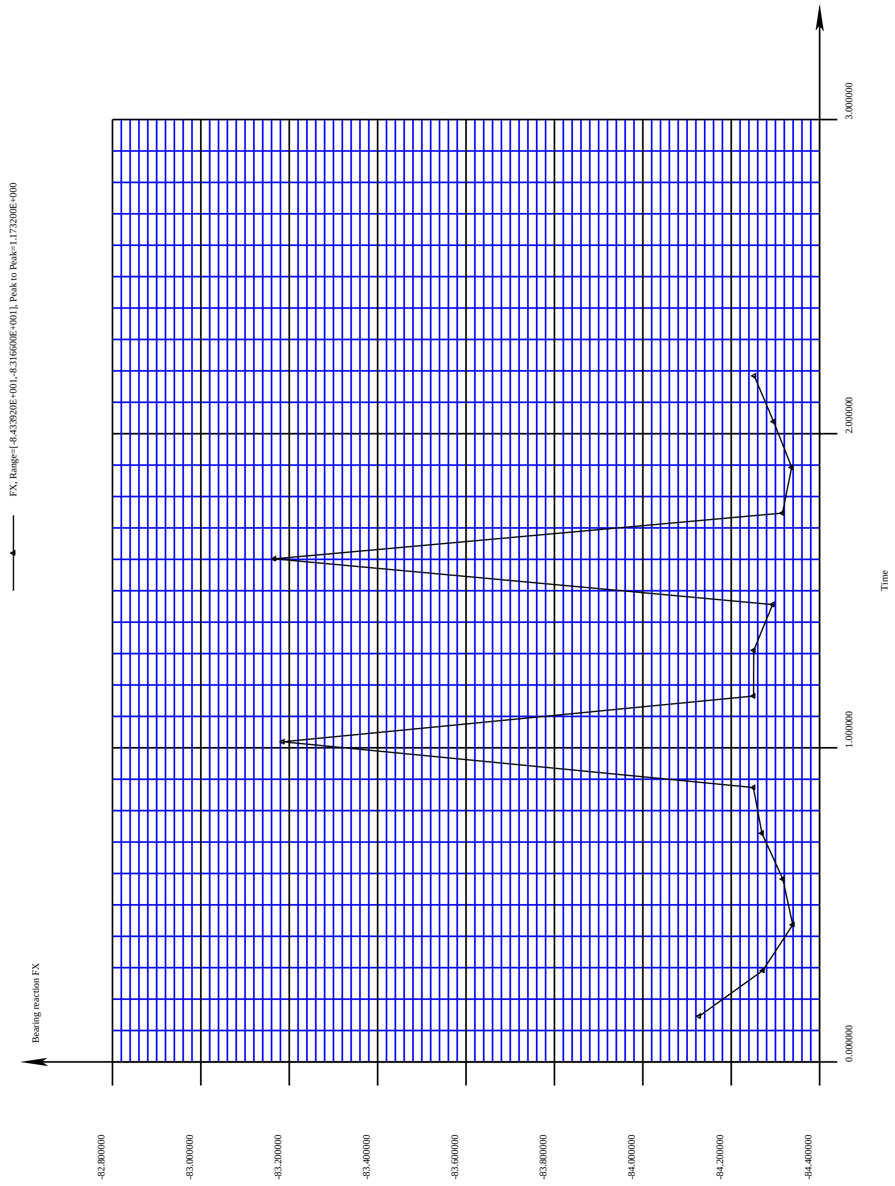
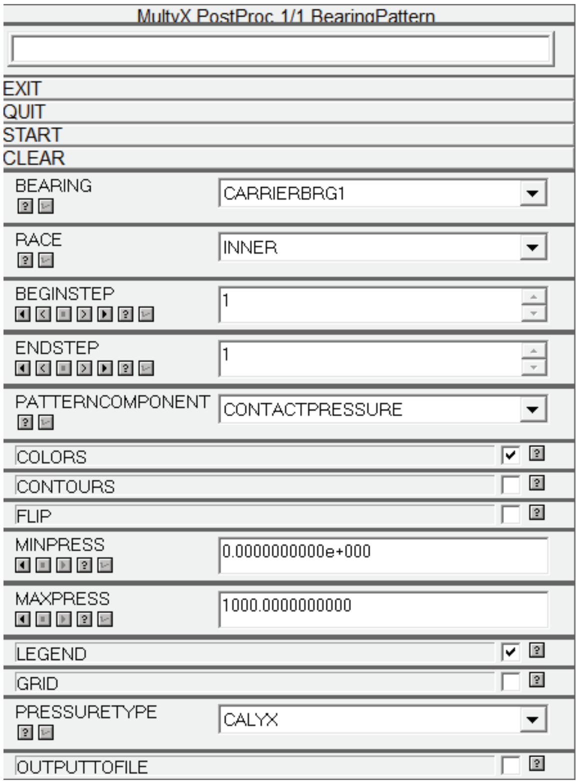


Figure 10.45 The graph generated by the BRGREACTION menu.


MultyX PostProc 1/1 BearingPattern
EXIT
QUIT
START
CLEAR

BEARING	CARRIERBRG1
RACE	INNER
BEGINSTEP	1
ENDSTEP	1
PATTERNCOMPONENT	CONTACTPRESSURE
COLORS	☑
CONTOURS	☐
FLIP	☐
MINPRESS	0.0000000000e+000
MAXPRESS	1000.0000000000
LEGEND	☑
GRID	☐
PRESSURETYPE	CALYX
OUTPUTTOFILE	☐

Figure 10.46 The BRGPATTERN menu.

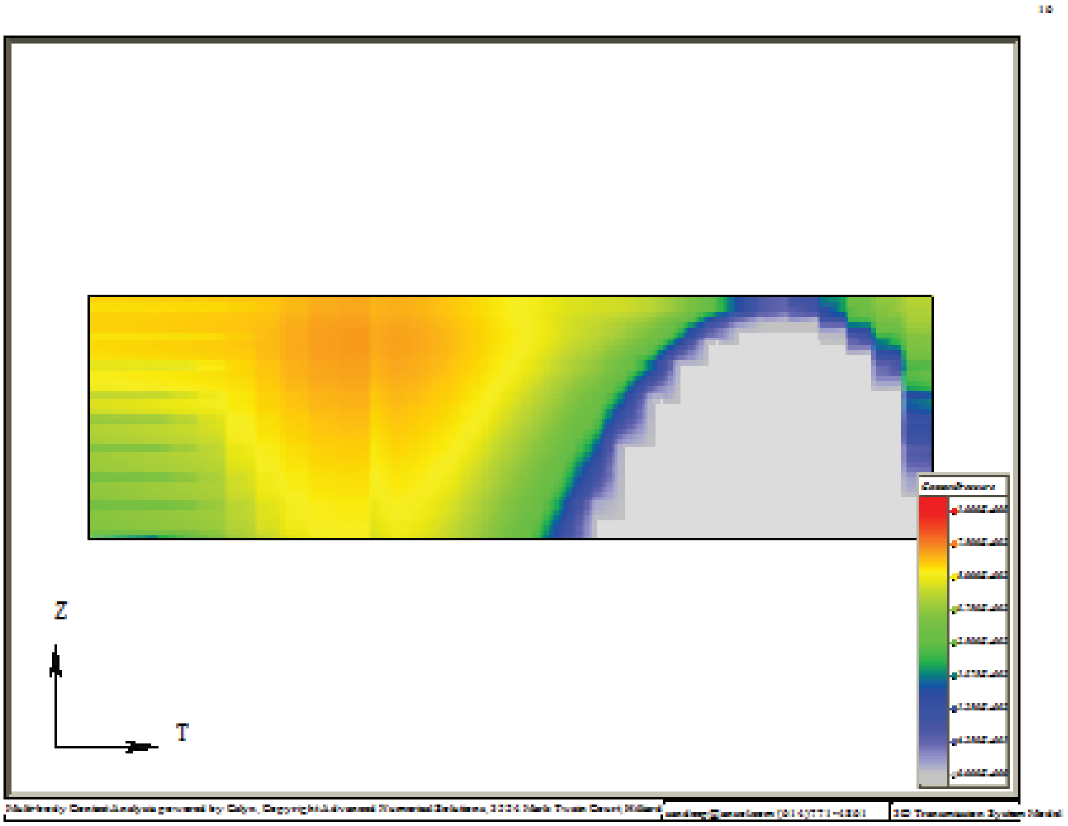
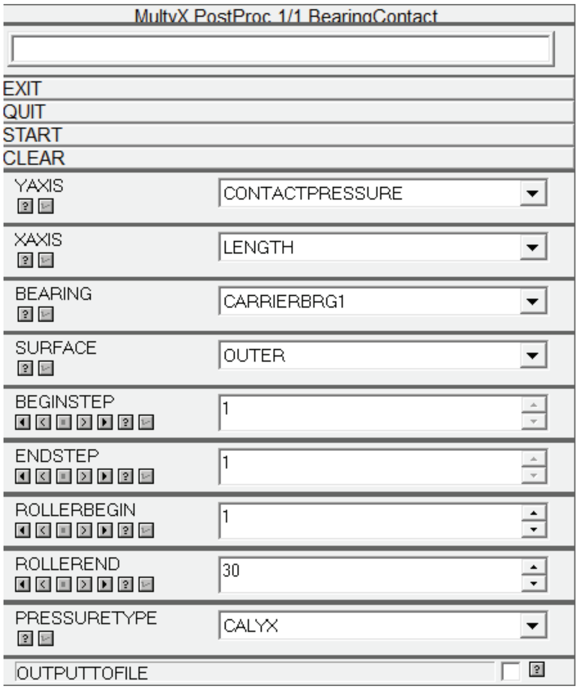


Figure 10.47 The bearing contact pattern.



YAXIS CONTACTPRESSURE
XAXIS LENGTH
BEARING CARRIERBRG1
SURFACE OUTER
BEGINSTEP 1
ENDSTEP 1
ROLLERBEGIN 1
ROLLEREND 30
PRESSURETYPE CALYX
OUTPUTTOFILE ☐

Figure 10.48 The BRGCONTACT menu.

10.22 The BRGCONTACT command

The BRGCONTACT postprocessing command leads to the menu shown in Figure 10.48. This menu can be used to generate a plot of contact pressure, load intensity, sub surface shear stress, or Von Mises sub surface stress vs either length or roller number. For the ’vs length’ plots, the values are taken for each contact grid in the length direction, and the maximum values at each length location are plotted for each roller as shown in Figure 10.49. For the ’vs roller’ plots, the maximum value on each roller is taken and plotted against the roller identification number as shown in Figure 10.50. The roller load plot can only be plotted vs roller ID since the load is a summation of the individual maximum grid loads in the length direction. The roller load vs roller plot is shown in Figure 10.51.

Table 10.1 The BRGCONTACT menu inputs.

Item	Description
YAXIS	Switch, The Y-axis variable to be plotted. Options are: CONTACTPRESSURE, LOADINTENSITY, SUBSURFACESHEAR, SUBSURFACEVONMISES, and ROLLERLOAD.
XAXIS	Switch, The X-axis variable to be plotted. Options are LENGTH and ROLLER. *Note: LENGTH is not an option when ROLLERLOAD is selected as the Y-axis variable, since ROLLERLOAD plots the total load on each roller.
BEARING	Switch, The name of the bearing for which the plot is desired.
SURFACE	Switch, The roller-race surface to sample data from. Options are INNER or OUTER.
BEGINSTEP	Integer, The time step to begin sampling data.
ENDSTEP	Integer, The time step to end sampling data.
ROLLERBEGIN	Integer, The roller number to begin sampling data.
ROLLEREND	Integer, The roller number to end sampling data.
OUTPUTTOFILE	Boolean, Enables the ability to write the data to a text file.

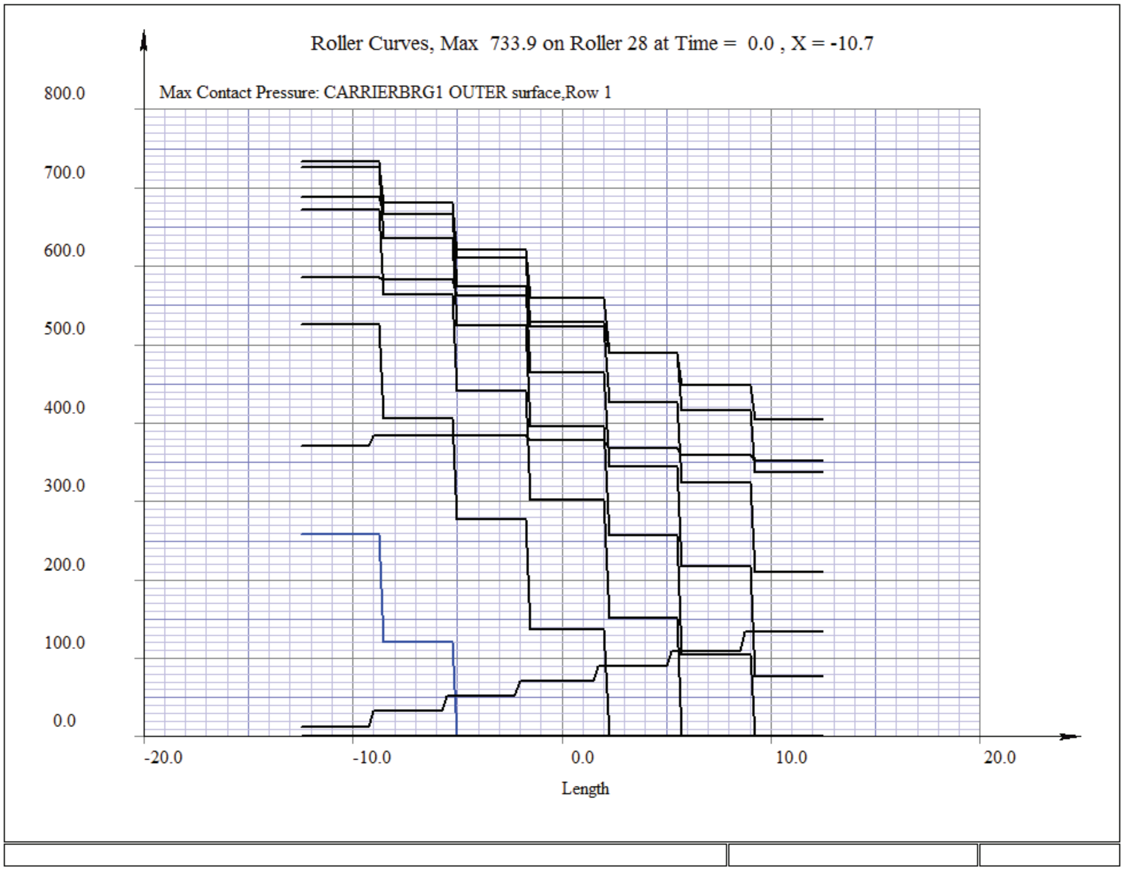


Figure 10.49 Contact pressure vs. length plot.

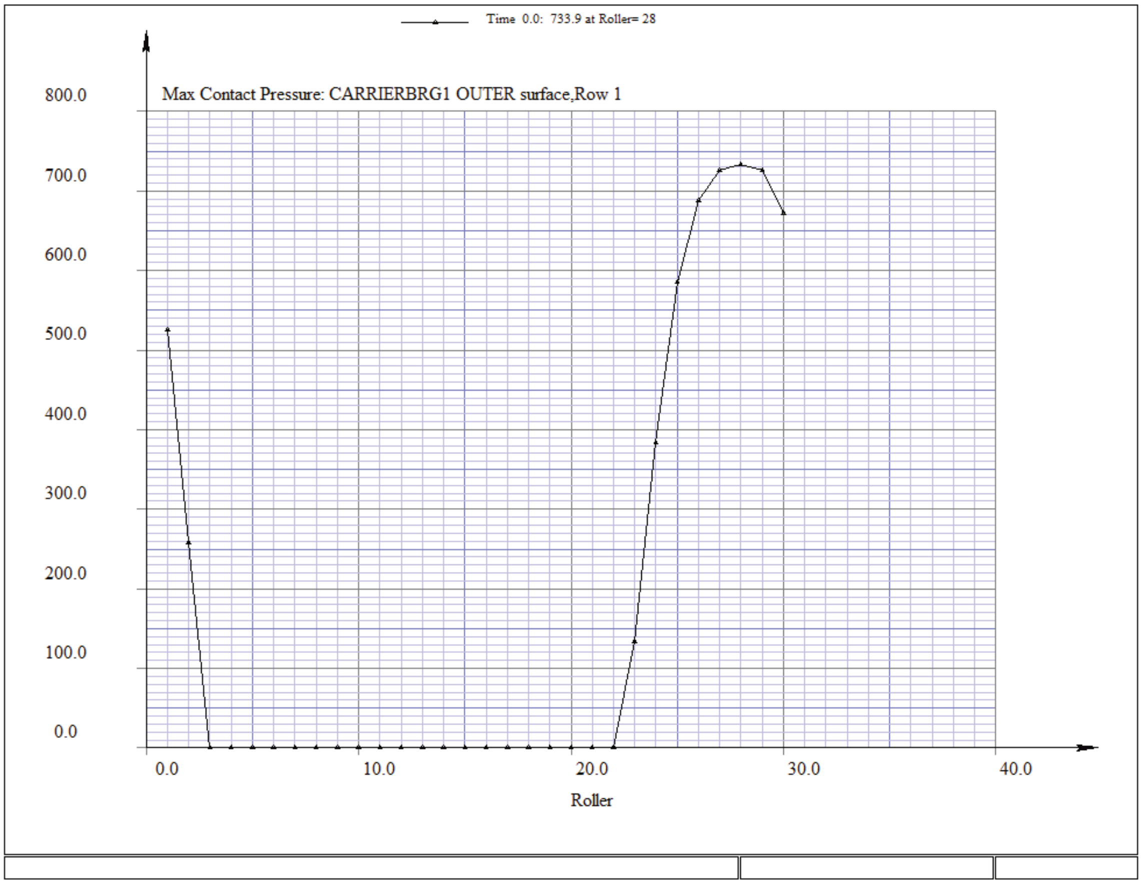


Figure 10.50 Contact pressure vs. roller plot.

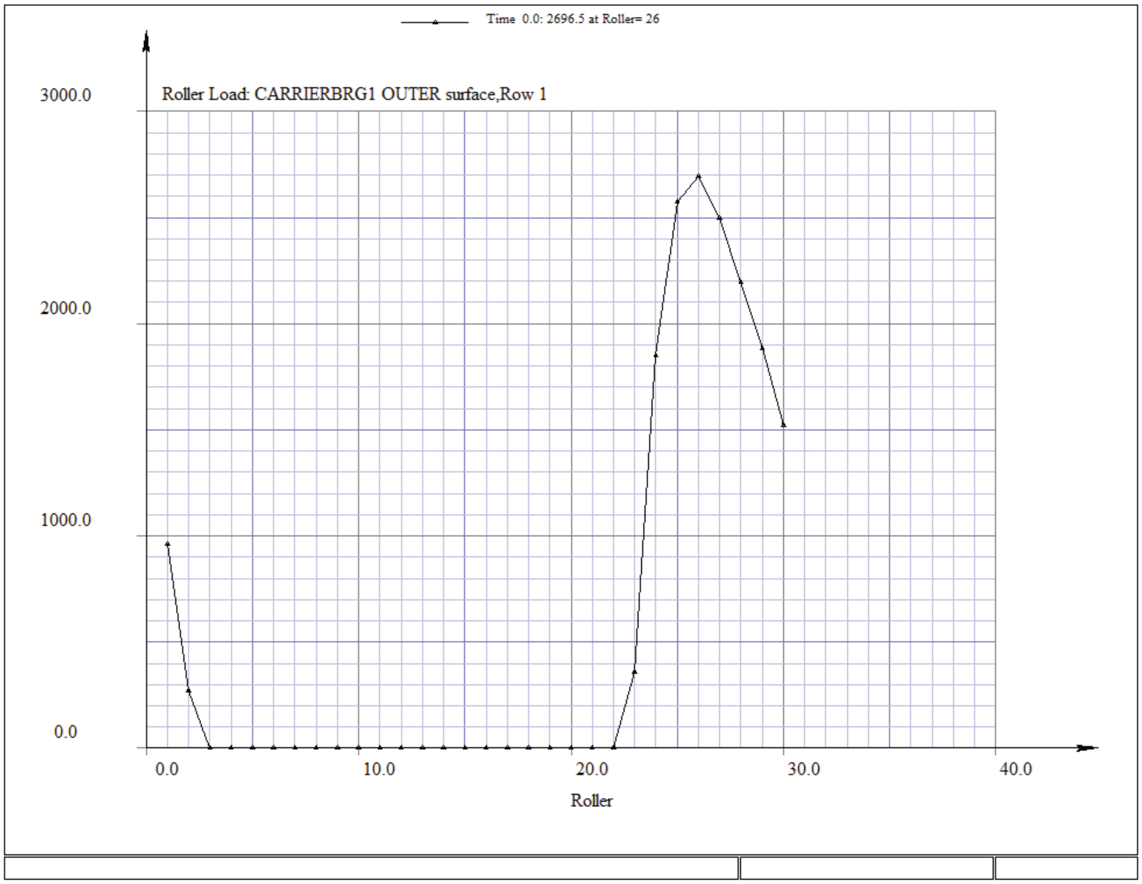
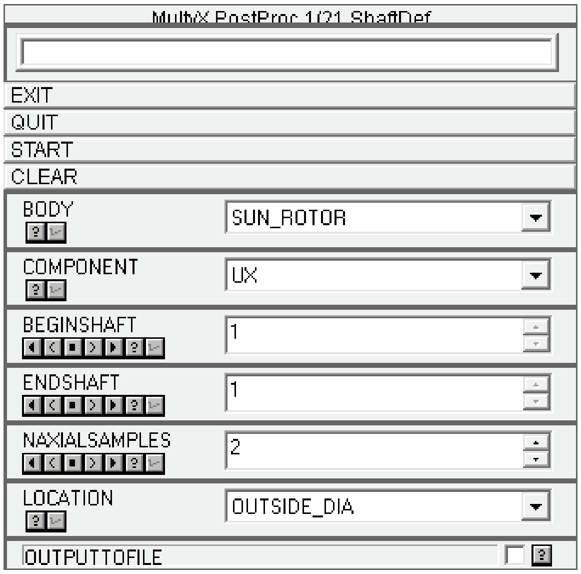


Figure 10.51 Roller load plot.



BODY SUN_ROTOR
COMPONENT UX
BEGINSHAFT 1
ENDSHAFT 1
NAXIALSAMPLES 2
LOCATION OUTSIDE_DIA
OUTPUTTOFILE ☐

Figure 10.52 Shaft Deformation Menu.

Table 10.2 The SHAFTDEFORMN menu inputs.

Item	Description
BODY	Switch, Selects the body.
COMPONENT	Switch, Selects the component of the shaft deformation.
BEGINSHAFT	Switch, The first shaft of interest.
ENDSHAFT	Switch, The last shaft of interest.
NAXIALSAMPLES	Integer, The number of samples over each finite element in the axial direction.
LOCATION	Switch, The surface location where the sample points are to be located.
OUTPUTTOFILE	Boolean, Enables user to output deformation data to a text file.

10.23 The SHAFTDEFORMN command

The shaft deformation postprocessing menu (Figure 10.52) allows the user to obtain the deformation of the shaft in the x, y or z directions on the inside or outside diameters of the shaft. The number of sample points along the length of the shaft is determined by the user to obtain the desired resolution. Deformation data can be output to a data file so that a deformation vs distance along shaft plot can be generated. Table 10.2 shows the description of each of the menu items.

CHAPTER 11

PRE AND POST PROCESSING USING IGLASSVIEWER

IglassViewer is a powerful tool for pre and postprocessing gear models and results. Several features have been added to the *Multyx* program to enhance the compatability with IglassViewer. Thus it can be considered as a program which enables the user to view pre and postprocessing files generated by an external code. Note that the IglassViewer graphics window is independent of the guide graphics window. The advantage of using IglassViewer over guide program for pre and postprocessing is that it is more faster, efficient and more simple to operate. Also, you can animate the models which is not possible using the Guide program. Following sections gives a detailed explanation of the procedure for creating the pre and postprocessing iglass files and also the various functions associated with the iglass program.

11.1 Generating an Iglass file for preprocessing

The GENIGLASSFILE command in Figure 10.1 will lead to a menu shown in Figure 11.1 using which you can generate a preprocessing file for Iglass. The filename is specified in the IGLASSFILENAME menu. The time at which the user wants to visualise the model can be specified in the TIME menu. The user can also visualise the model at a sequence of time steps by entering the number of steps in the NTIMESTEPS menu. The DELTATIME menu is the value of time increment between successive writes to the iglass file. The POPUPIGLASS menu if turned on will automatically open up the Iglass graphical window after the Igass file is generated. If it is not turned on, only the data file for iglass will be created, and iglass will have to be started manually. Using the SELECT menu in Figure 11.1 the user can select the bodies to be displayed in the Iglass graphical window. Click on the START button in Figure 11.1 to generate the Iglass preprocessing file. After the file is generated and if the POPUPIGLASS menu is turned on a separate Iglass window will open showing the reference axes and the gear bodies (selected in the SELECT menu). An example of the Iglass preprocessing window for a planetary system is shown in Figure 11.2. As shown in Figure, it has 3 menus- View, Bodies and Attributes. The Attributes menu is used more commonly in the postprocessing mode. The ‘Exit’ button in each menu will close the Iglass graphics window.

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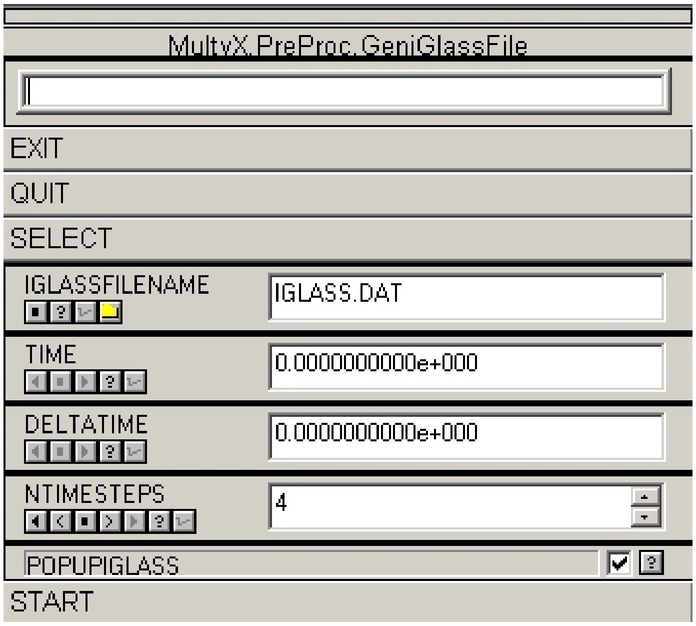

MultyX.PreProc.GeniGlassFile
EXIT
QUIT
SELECT
START

IGLASSFILENAME IGLASS.DAT

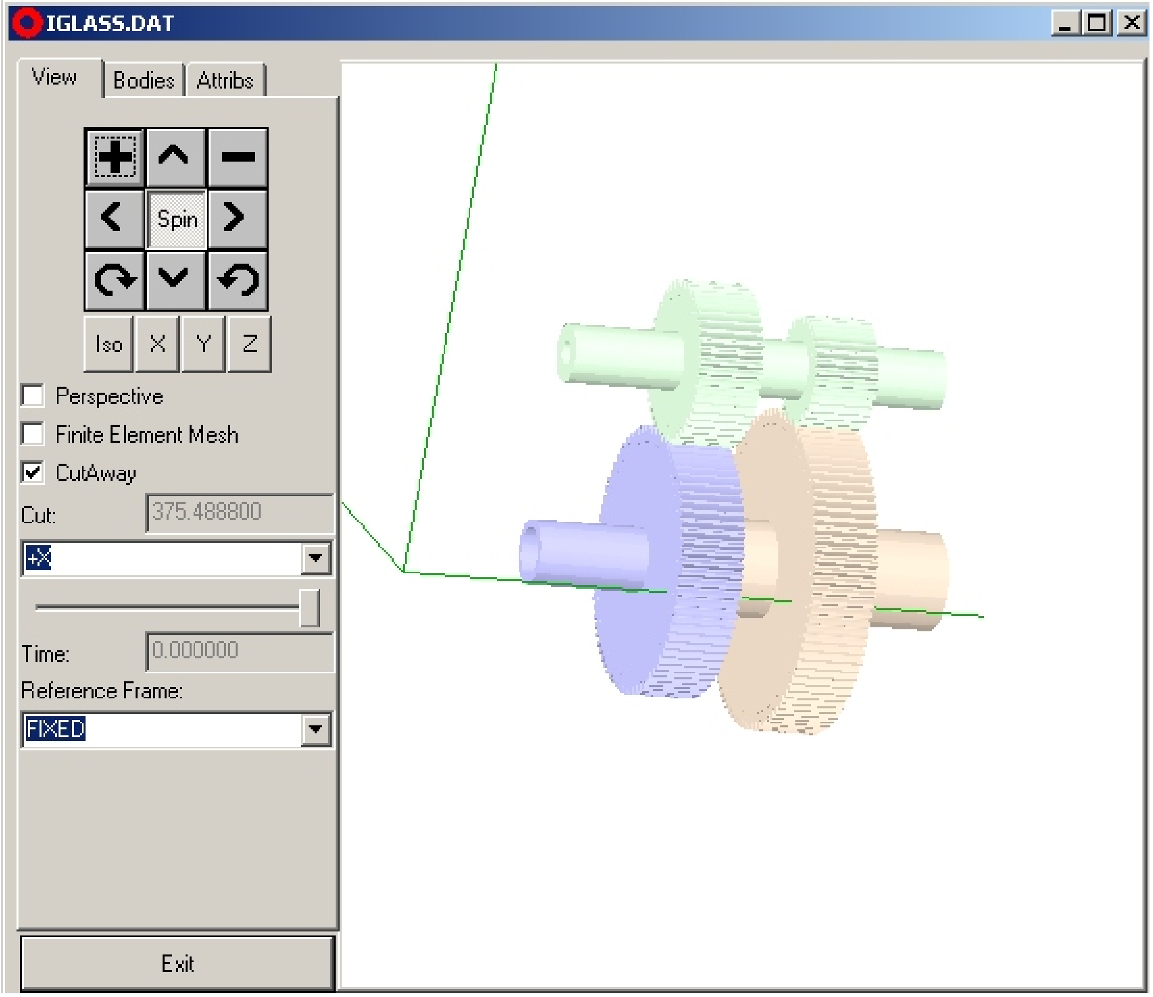
TIME 0.0000000000e+000

DELTATIME 0.0000000000e+000

NTIMESTEPS 4

POPUPIGLASS ☑

Figure 11.1 The generate Iglass file menu


View
Bodies
Attribs
Spin
Iso
X
Y
Z
Exit

IGLASS.DAT

☐ Perspective

☐ Finite Element Mesh

☑ CutAway

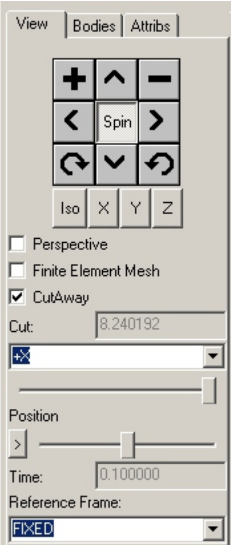
Cut: 375.488800

+X

Time: 0.000000

Reference Frame: FIXED

Figure 11.2 An example of an Iglass preprocessing window.



☐ Perspective
☐ Finite Element Mesh
☑ CutAway
Cut: 8.240192
+X
Time: 0.100000
Reference Frame: FIXED

Figure 11.3 Iglass preprocessing view menu

11.2 View menu

The View menu is shown in Figure 11.3. Table 11.1 shows the common tasks performed by some of the buttons displayed in this menu.

Apart from all the features shown in Table 11.1 you can also rotate the model using the left mouse button. Drag the left mouse button in the direction you want to rotate the model in the iglass graphics window. Also the model can be moved in the graphics window in any directions you want using the right mouse button. Drag the right mouse button in the direction you want to move the model in the iglass graphics window.

11.2.1 Finite element mesh

The finite element mesh model can be visualised if the ‘Finite Element Mesh’ item is selected. Figure 11.4 shows the finite element mesh model of the gear bodies in iglass preprocessing.

11.2.2 Cutting plane

Using the cutting plane switch shown in Figure 11.5 you can visualise the model along a section. This feature is especially useful in pre and post processing of complicated models with a large number of internal gears. The cutting plane can be selected along the +ve and -ve X, Y and Z axes. Using the button below the cutplane switch you can select the cutting plane at various points along the axis chosen by the cut plane switch option.

11.2.3 Selecting the time step

User can visualise the model at a particular timestep in iglass pre-processing using the ‘Position’ slider shown in Figure 11.6. Each position corresponds to the DELTATIME selected in the generate iglass file menu. The corresponding time can be seen in the ‘Time’ item shown in Figure 11.7.

11.2.4 Reference frames

The default reference frame is the FIXED reference frame. All the bodies appear to move when observed from the FIXED frame. The model will align itself to this reference frame when the iglass window pops up.

Table 11.1 Common buttons in Iglass pre and postprocessing window

Button	Purpose
+	Zoom In
−	Zoom Out
^	Move the model upwards (If Spin is turned OFF)
˅	Move the model downwards (If Spin is turned OFF)
>	Move the model towards right (If Spin is turned OFF)
<	Move the model towards left (If Spin is turned OFF)
^	Rotate the model upwards (If Spin is turned ON)
˅	Rotate the model downwards (If Spin is turned ON)
>	Rotate the model towards right (If Spin is turned ON)
<	Rotate the model towards left (If Spin is turned ON)
⟳	Rotate the model clockwise (If Spin is turned ON)
⟲	Rotate the model counterclockwise (If Spin is turned ON)
Iso	View the model in an isometric view
X	View the model in the $Y - Z$ plane
Y	View the model in the $X - Z$ plane
Z	View the model in the $X - Y$ plane

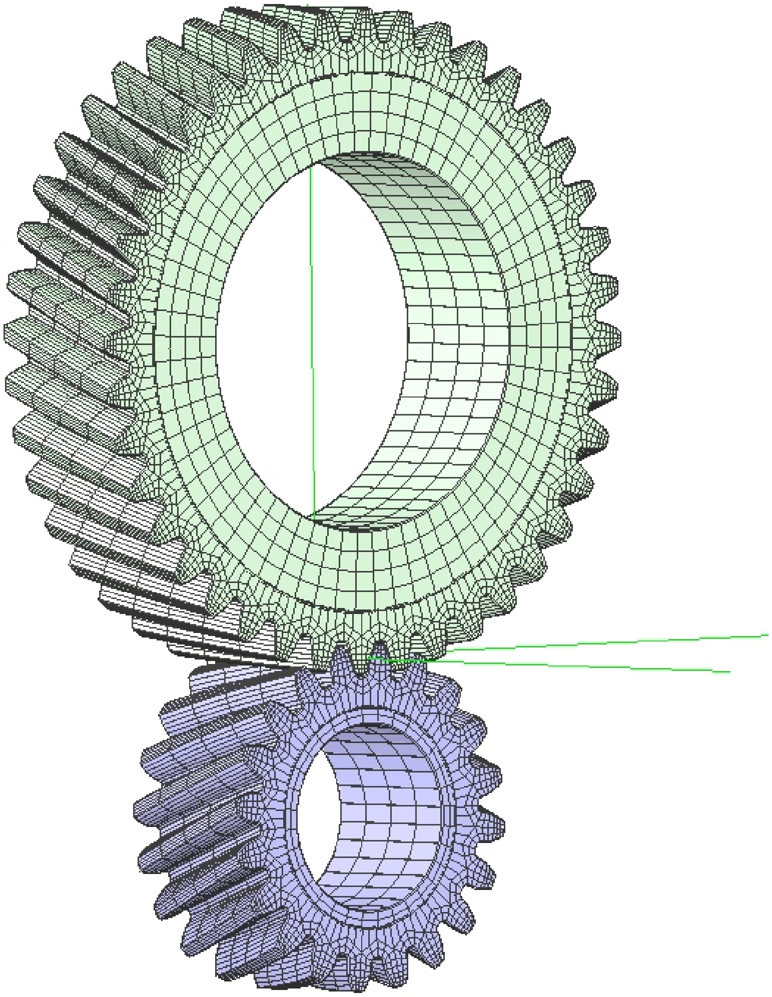
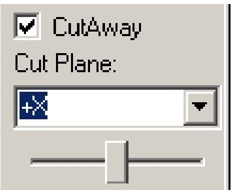


Figure 11.4 Finite element mesh model of the gear bodies



☑ CutAway

Cut Plane: +X

Figure 11.5 The cutting plane switch.

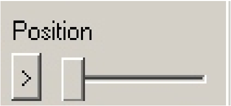
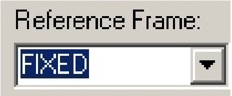


Figure 11.6 The position slider.

Time:
0.000000

Figure 11.7 The time menu.



Reference Frame:
FIXED

Figure 11.8 The reference frame switch.

The reference frame can be aligned to a body member using the reference frame switch shown in Figure 11.8. If you select the SUN gear as the reference frame the reference frame origin will coincide with the origin of the sun. The sun will appear stationary when observed from the SUN reference frame, and the other bodies orbit around it. If the PINION option is selected then the reference frame origin aligns itself to the origin of the pinion.

11.3 The Bodies menu

The 'Bodies' menu is shown in Figure 11.9. The body member can be turned on or off by clicking on the member name in the Bodies menu. User can view the tooth and the rim sector separately for each gear body.

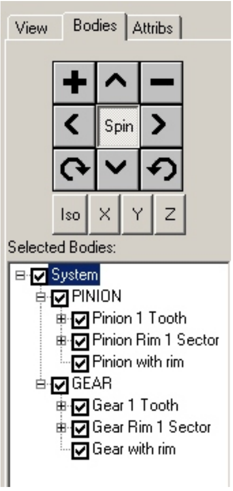
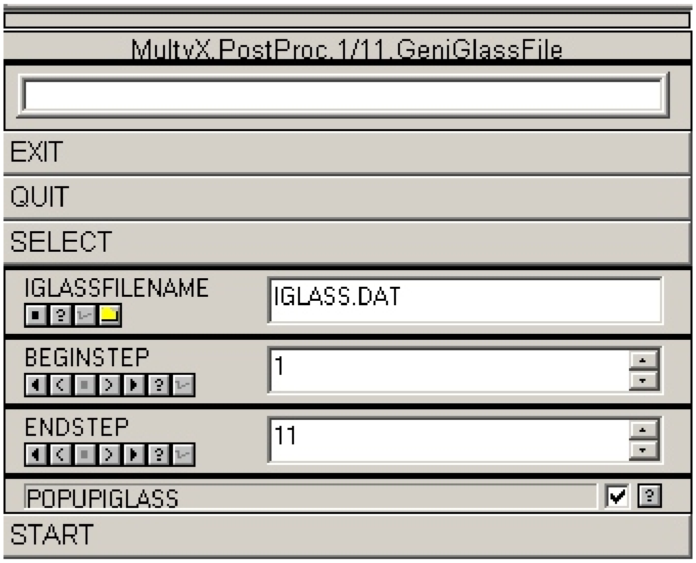

View
Bodies
Attribs
Spin
Iso
X
Y
Z
Selected Bodies:
☑ System
☑ PINION
☑ Pinion 1 Tooth
☑ Pinion Rim 1 Sector
☑ Pinion with rim
☑ GEAR
☑ Gear 1 Tooth
☑ Gear Rim 1 Sector
☑ Gear with rim

Figure 11.9 Iglass preprocessing Bodies menu



IGLASSFILENAME: IGLASS.DAT

BEGINSTEP: 1

ENDSTEP: 11

POPUPIGLASS ☑

Figure 11.10 The generate iglass file menu for post processing.

11.4 Post processing using iglass

The GENIGLASSFILE command in Figure 10.3 leads to the generate iglass file menu shown in Figure 11.10 for post processing in iglass. BEGINSTEP and ENDSTEP menus shown in Figure 11.10 define the range for which you want to check for results. Note that these menus are independent of the GOTOPOSN menu shown in Figure 10.3.

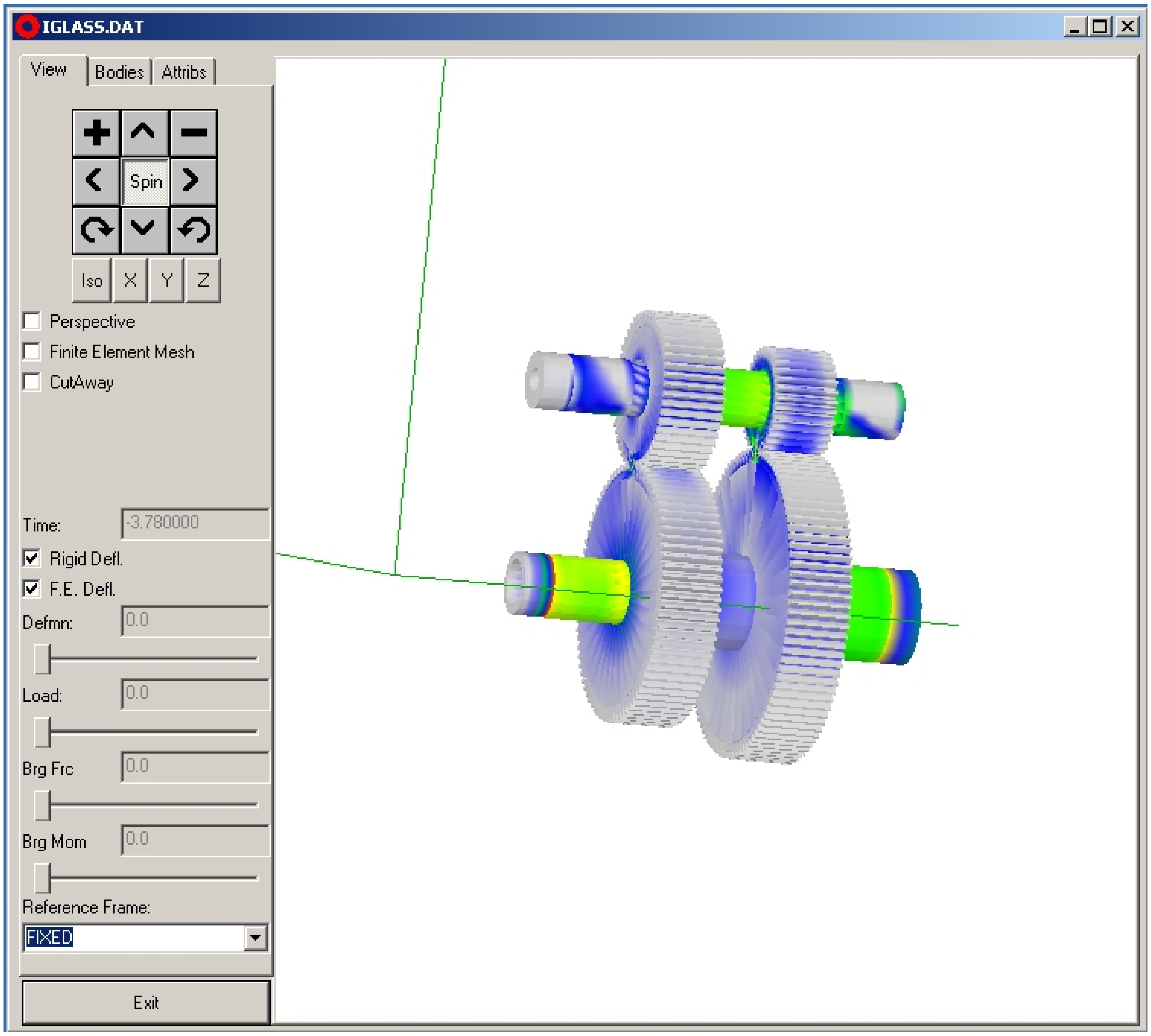
An example of an iglass post processing window is shown in Figure 11.11.

11.5 Features specific to iglass post processing

The position switch shown in Figure 11.12 is used to run the simulation of the model in the post processing iglass window. You can look at the simulation at a particular time step by dragging the slider along the scale. The ‘Defmn’(deformation) slider shown in Figure 11.13 is used to view the deformed shaped of the gear bodies. The ‘Rigid Defl’ and the ‘F.E.Defl’ shows the rigid body deflection and the finite element deflection of the bodies. The magnification scale of deformation can be adjusted using the slider. The load slider shown in Figure 11.14 is used to look for the load patterns on a tooth over the range of time step selected in the BEGINSTEP and ENDSTEP menus. The magnification scale of loading can be adjusted using the slider. The directions of the bearing forces and moments can be visualised using the ‘Brg Frc’ and ‘Brg Mom’ sliders shown in Figure 11.15. The magnification scale of the forces and the moments can be adjusted using the respective sliders.

The ‘Attribs’ menu is shown in Figure 11.16. The attribute menu shown in Figure 11.17 is used to check for contours for different component of results. The available options are DISPLVECTOR, MAXPPLNORMAL, S2PPLNORMAL, MINPPLNORMAL, MAXSHEAR, VONMISES and ERRORESTIMATE. The DISPLVECTOR will pop up a component switch using which the contour for displacement vector in the X, Y and Z directions can be displayed. MAXPPLNORMAL, S2PPLNORMAL, MINPPLNORMAL, MAXSHEAR, VONMISES menus show their respective stress contours. The ERRORESTIMATE menu is used to display the stress error estimate. This error estimate is computed from the magnitude of the inter-element stress discontinuity.

The colors for minimum and maximum stress contours can be controlled using the palette mode menu shown in Figure 11.18. A POSITIVE mode will align the scale from 0 (minimum stress) to a maximum positive value (maximum stress). A NEGATIVE mode will align the scale from 0 to a negative value. The


IGLASS.DAT
View
Bodies
Attribs
Spin
Iso
X
Y
Z
Exit

☐ Perspective
☐ Finite Element Mesh
☐ CutAway
Time: -3.780000
☑ Rigid Defl.
☑ F.E. Defl.
Defmn: 0.0
Load: 0.0
Brg Frc 0.0
Brg Mom 0.0
Reference Frame: FIXED

Figure 11.11 An example of an iglass post processing window.

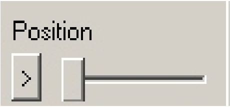
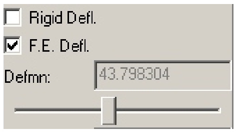
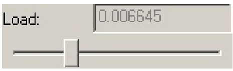


Figure 11.12 The position slider.



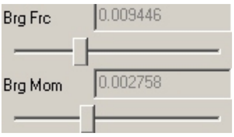
☐ Rigid Defl.
☑ F.E. Defl.
Defmn: 43.798304

Figure 11.13 The deformation slider.



Load: 0.006645

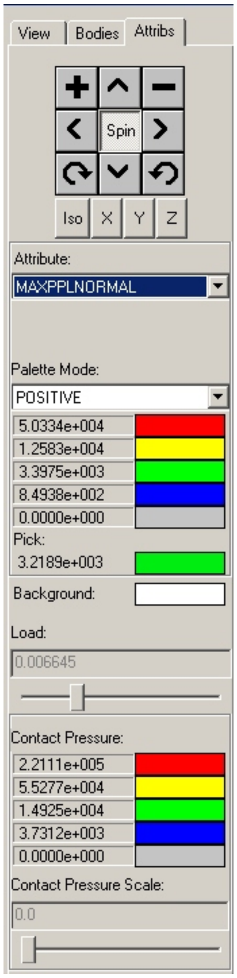
Figure 11.14 The load slider.



Brg Frc 0.009446

Brg Mom 0.002758

Figure 11.15 The bearing forces and moments sliders.



Attribute: MAXPPLNORMAL

Palette Mode: POSITIVE

5.0334e+004 🟥
1.2583e+004 🟨
3.3975e+003 🟩
8.4938e+002 🟦
0.0000e+000 ⬜

Pick:
3.2189e+003 🟩

Background: ⬜

Load: 0.006645

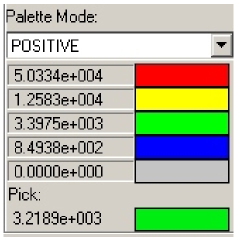
Contact Pressure:
2.2111e+005 🟥
5.5277e+004 🟨
1.4925e+004 🟩
3.7312e+003 🟦
0.0000e+000 ⬜

Contact Pressure Scale: 0.0

Figure 11.16 The iglass postprocessing attribute menu.

Attribute: NONE

Figure 11.17 The attribute switch.



Palette Mode:

POSITIVE

5.0334e+004	🟥
1.2583e+004	🟨
3.3975e+003	🟩
8.4938e+002	🟦
0.0000e+000	⬜

Pick:

3.2189e+003	🟩

Figure 11.18 The palette switch.

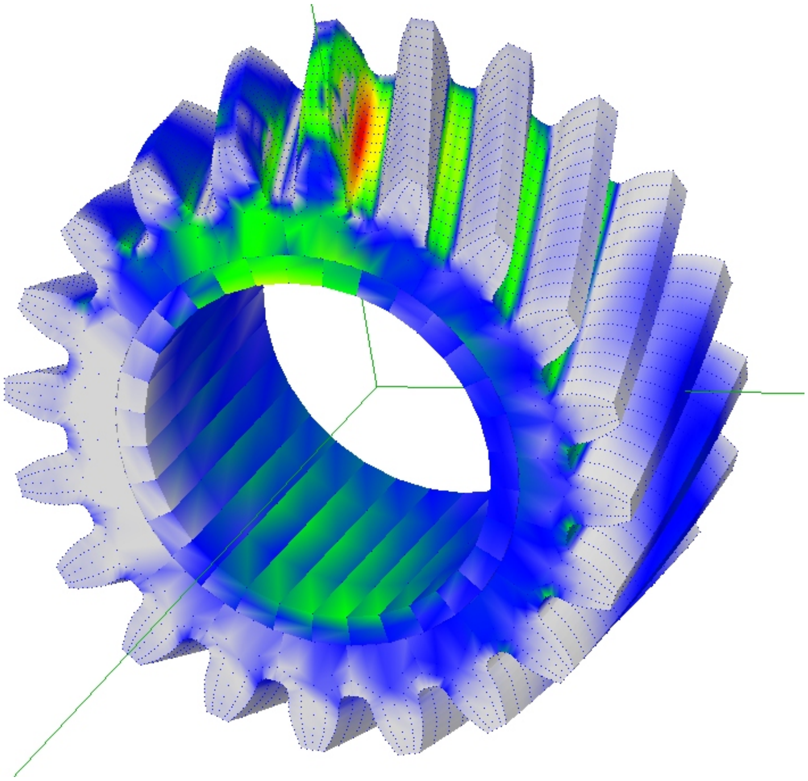
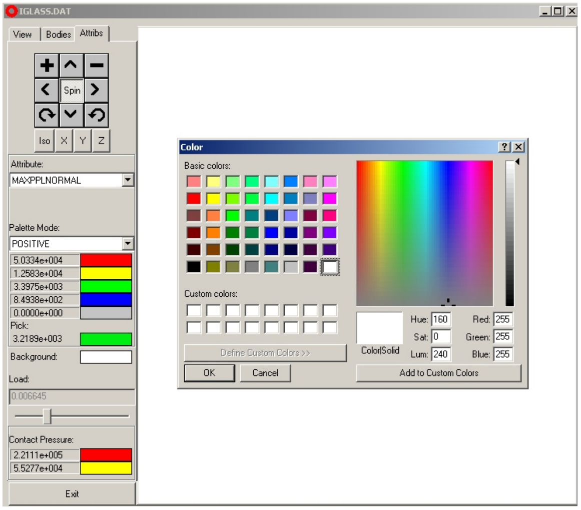


Figure 11.19 Picking the stress value at a nodal point of the finite element mesh


IGLASS.DAT
View
Bodies
Attribs
Spin
Iso
X
Y
Z
Color
Basic colors:
Custom colors:
Define Custom Colors >>
OK
Cancel
Color|Solid
Add to Custom Colors
Exit

Attribute: MAXPPLNORMAL

Palette Mode: POSITIVE

5.0334e+004	🟥
1.2583e+004	🟨
3.3975e+003	🟩
8.4938e+002	🟦
0.0000e+000	⬜

Pick: 3.2189e+003 🟩

Background: ⬜

Load: 0.006645

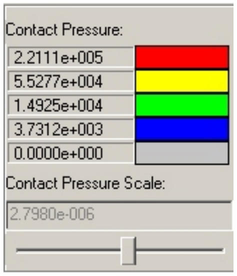
Contact Pressure:

2.2111e+005	🟥
5.5277e+004	🟨

Hue: 160 Sat: 0 Lum: 240

Red: 255 Green: 255 Blue: 255

Figure 11.20 The background color popup window switch.



Contact Pressure:

2.2111e+005	🟥
5.5277e+004	🟨
1.4925e+004	🟩
3.7312e+003	🟦
0.0000e+000	⬜

Contact Pressure Scale: 2.7980e-006

Figure 11.21 The Contact pattern menu.

BOTH type mode will align the scale from the maximum negative value (minimum stress) to a maximum positive value (maximum stress). In order to find the stress at a node, double click on the gear body. The finite element nodes are now visible as shown in figure 11.19. Clicking once on the node will show the stress at that nodal point in the ‘pick’ item of the Palette menu.

Double clicking on the ‘Background’ button will popup the ‘Color’ window shown in Figure 11.20 using which you can change the background color of the iglass graphics window.

The Contact pattern menu shown in Figure 11.21 is used to view the contact pressure pattern on the contacting surfaces. Figure 11.22 shows an example of a contact pattern on the gear tooth.

The EXIT button will take you out of the iglass post processing window.

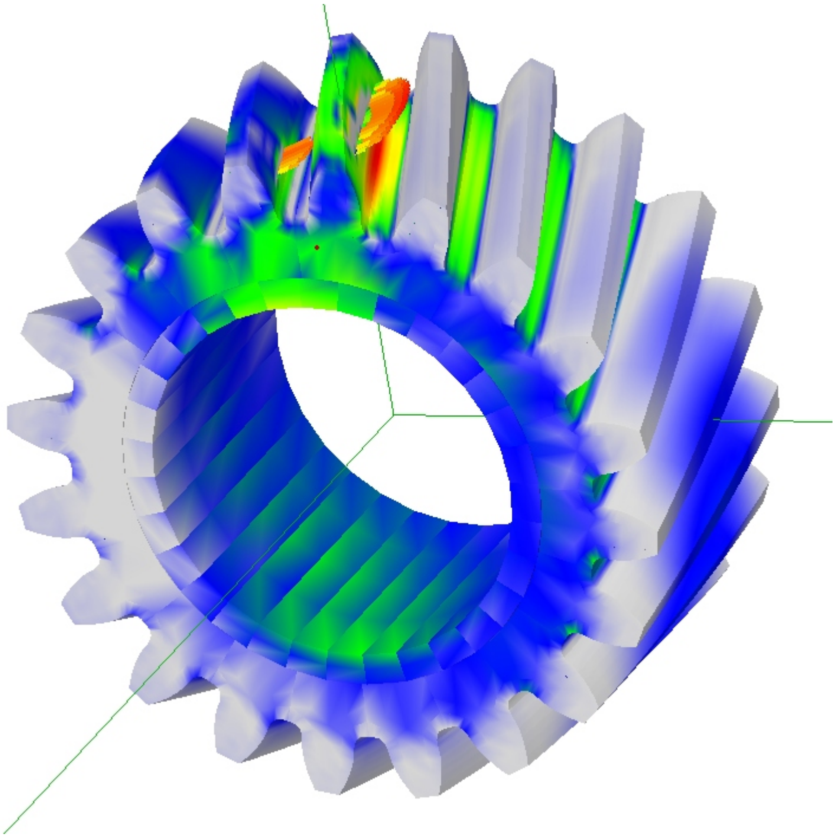


Figure 11.22 Example of a contact pattern on a gear tooth

APPENDIX A

TOOTH MESH TEMPLATES

The finite element meshes in the $Transmission3D$ package are created with very little input from the user. The user does not need to provide any of the node numbering and element connectivity information to the model generator. This information is read by the program from pre-existing files called ‘template’ files.

Figures A.1 through A.4 show the element connectivity and element numbering scheme used in the four standard templates. The orientation of the element coordinate system is indicated by the notch in one of the corners of each element. The range of the surface profile coordinate s for the two contact surfaces is also shown.

The element orientation for the rim sector is shown in Figure A.5.

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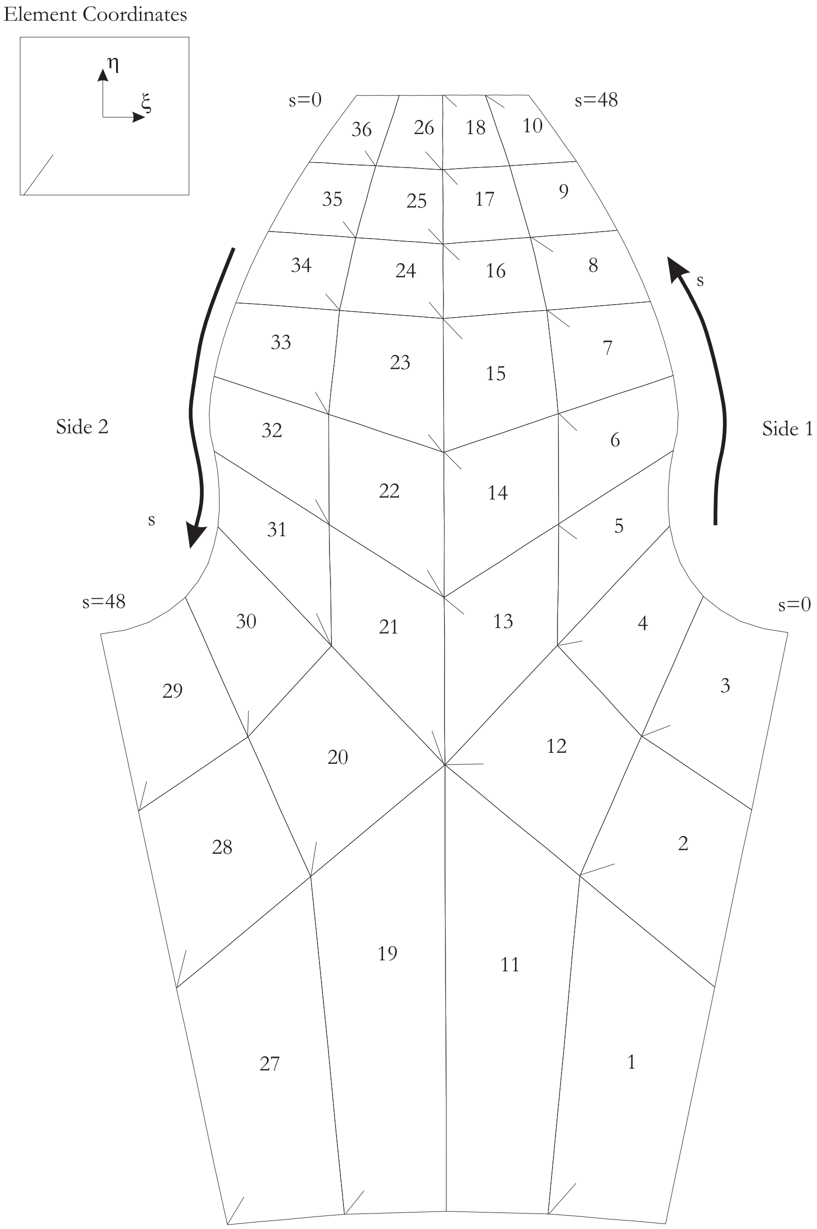
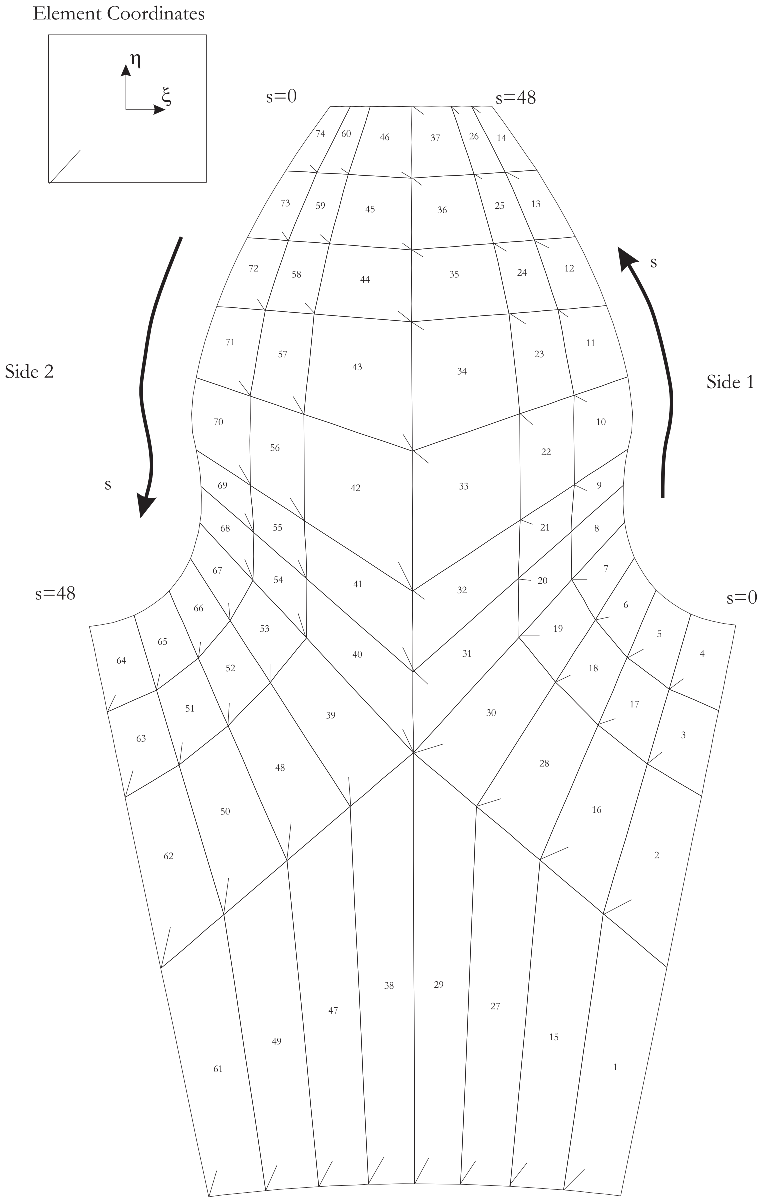

Element Coordinates
η
ξ
s=0
s=48
Side 2
Side 1
s
s
s=48
s=0
36
26
18
10
35
25
17
9
34
24
16
8
33
23
15
7
32
22
14
6
31
5
30
21
13
4
29
3
20
12
28
2
19
11
27
1

Figure A.1 The MEDIUM.TPL template file.


Element Coordinates
η
ξ
s=0
s=48
s
Side 2
Side 1
s
s=48
s=0
74
60
46
37
26
14
73
59
45
36
25
13
72
58
44
35
24
12
71
57
43
34
23
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41
32
20
7
66
6
53
19
65
5
64
52
40
31
18
4
51
17
63
39
30
3
48
28
50
16
62
2
38
29
47
27
49
15
61
1

Figure A.2 The FINEROOT.TPL template file.

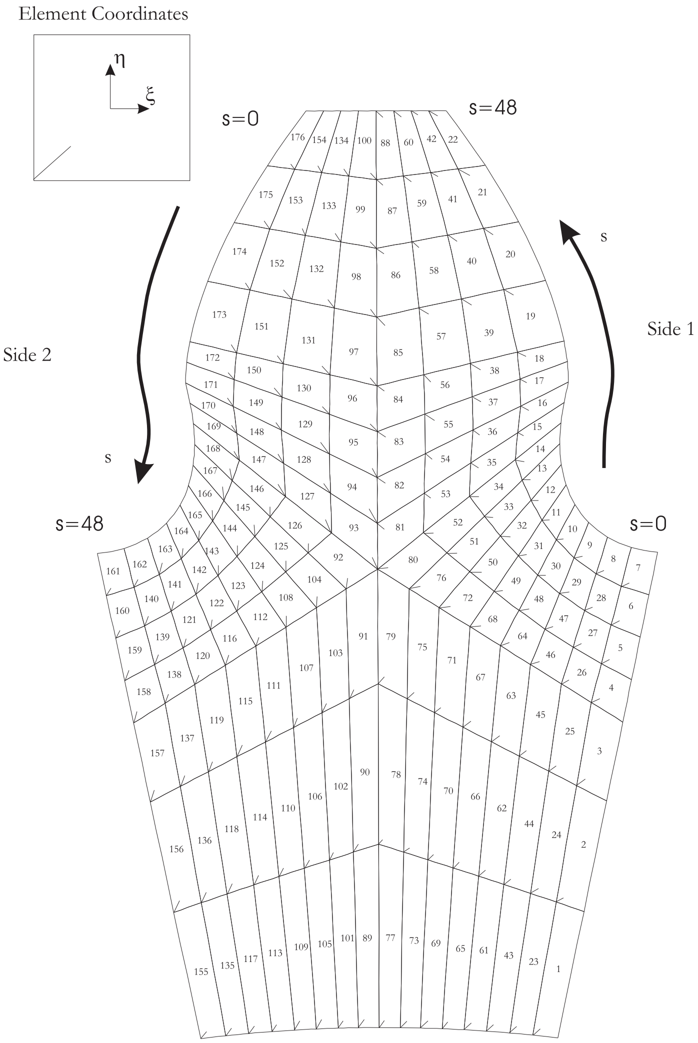
Element Coordinates
η
ξ
s=0
s=48
Side 2
s
s=48
s
Side 1
s=0

Figure A.3 The FINEST.TPL template file.

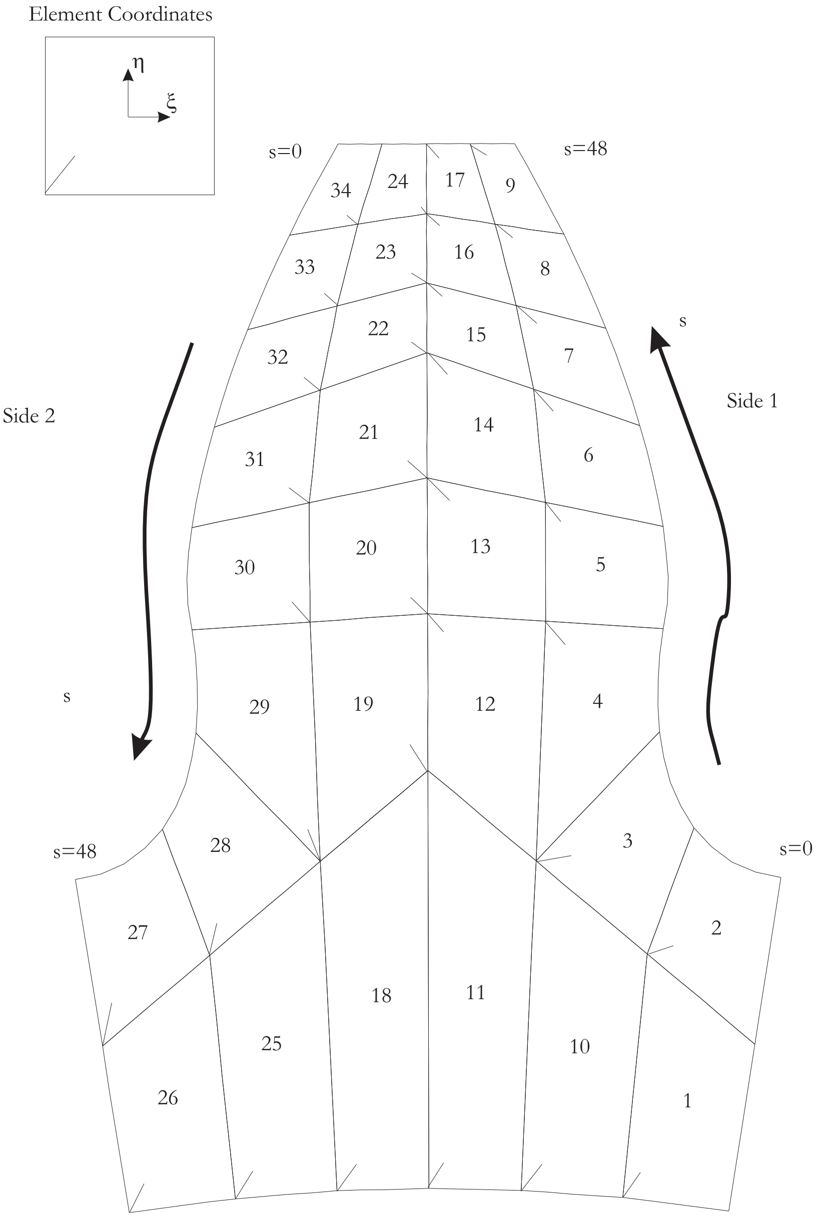
Element Coordinates
η
ξ
s=0
s=48
Side 2
Side 1
s
s
s=48
s=0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
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Figure A.4 The THINRIM.TPL template file.

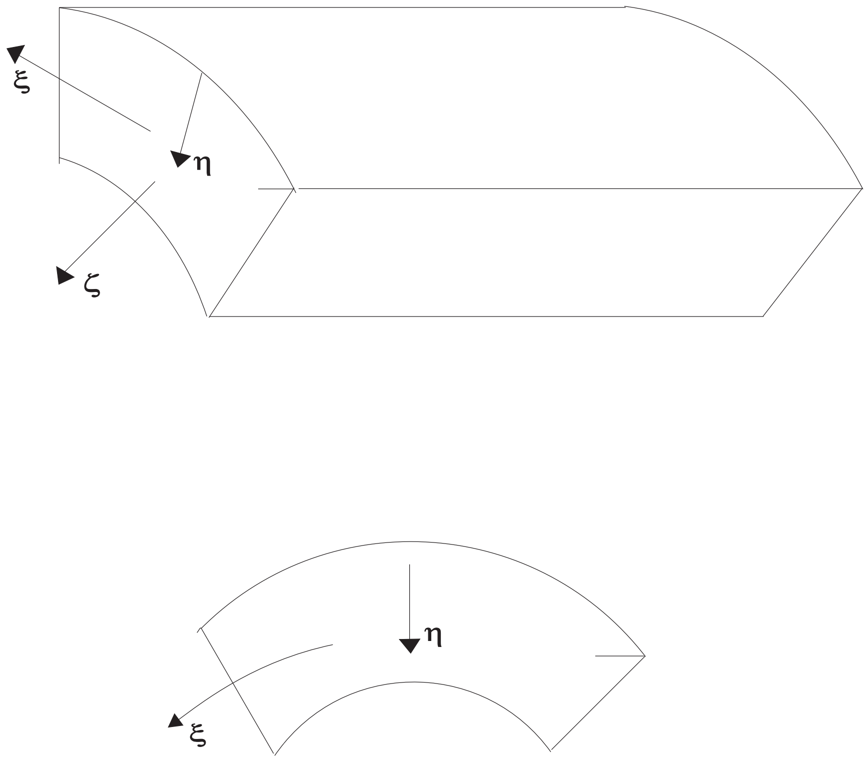

Figure A.5 Element orientation for the rim sector

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